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# PERTH WATER SUPPLY.

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The Perth Metropolitan Water Supply Area comprises the City of Perth, the Municipalities of Fremantle, North Fremantle, Claremont, Subiaco, Guildford and Midland Junction and portions of the Road Districts along the Swan River between Fremantle and Midland Junction and along the Canning River from Perth to Armadale (Fig. 1). The Water Supply for the whole of this area is controlled by the Metropolitan Water Supply Department, under the direction of the Minister for Water Supply. The area at present supplied is about 70 square miles and has a population of about 190,000.

The greater part of the area is comparatively low-lying country, portion of the coastal plain between the sea and the Darling Range, the highest elevation being 236 feet above sea level on Mt. Eliza. There is very little of the area over 200 feet elevation. The coast is fringed with a narrow strip of sand dunes, and, behind these, a zone about 2 miles wide of sand and limestone hills frequently rising to a height of 200 feet. Eastward of the limestone zone is a zone of drift sand about 10 miles wide, on which stands the City of Perth, and east of this a zone two to three miles wide of clay along the foot of the Hills—the Darling Range—which run roughly parallel with and 15 to 16 miles distant from the coast. The Darling Range, or rather plateau, is composed mainly of granite seamed with basic dykes and capped with laterite and rises to a general maximum elevation of about 1,000 feet.

Underlying the coastal plain is an artesian basin with artesian water-bearing strata at various depths from 430 to 2,097 feet—the greatest depth so far sunk—and possibly deeper.

The Darling Range comprises the catchment areas on which the city must rely in the future for its main source of Water Supply.

The most northerly catchment area from which a potable supply in quantity is available is that of the Helena River, on

which is situated the Mundaring Reservoir of the Goldfields Water Supply. This river emerges from the Hills on to the coastal plain, about 11 miles from Perth. Next to the Helena is the catchment of Victoria Reservoir on Munday Brook, from which the first Hills water supply for Perth was drawn in 1890. Immediately south of Munday Brook is the Canning River, then Wungong Brook, and the Serpentine River which flows from the foot hills at a distance of 28 miles from Perth.

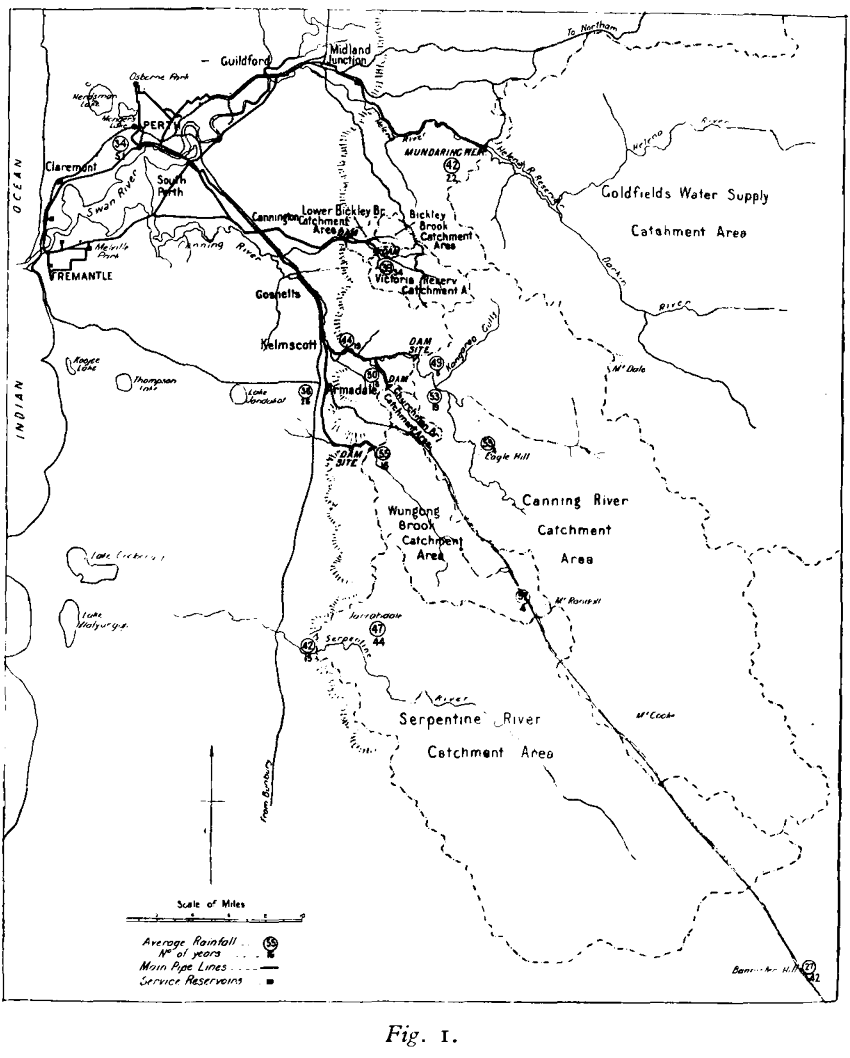



*Fig.* 1.

The areas and approximate average rainfalls on the various catchments are as follows :—

| Reservoir | | Area of Catchment sq. miles. | Approximate average Rainfall inches |
|---|---|---|---|
| Mundaring | ... | 569 | 30 |
| Victoria ... | ... | 14.5 | 40 |
| Canning ... | ... | 315 | 45 |
| Churchman... | ... | 6 | 50 |
| Wungong ... | ... | 50 | 52 |
| Serpentine ... | ... | 300 | 40 |

### *Early Water Supplies.*

From the foundation of the settlement, in 1829, to 1890 the water supplies for the various separate communities were drawn from springs and wells, but with increasing settlement and consequent pollution of the ground water, it was found necessary to provide sources free from pollution for reticulated water supplies, first for Perth in 1891 (from Victoria Reservoir), for Fremantle in 1902 (from artesian bores), and in 1904 for Claremont and Cottesloe (from artesian bores).

The Victoria Reservoir has a capacity of 212 million gallons. The dam of this reservoir is arched, built of concrete, 750 feet long, with an arch radius of 400 feet, and has a maximum height of 104 feet from foundation on granite rock. The greatest depth of water impounded is 52 feet. The dam is provided with a bywash at each end, 2 ft. deep, one 27ft. 3 in. long and the other 27 ft. 9 in. long. The elevation of the overflow is 593.6 feet above low water mark Fremantle. The top width of the dam is 3 ft. 6 in. The upstream face is vertical for a depth of 10 feet from the top and is then battered 1 to 20 to foundation. The thicknesses of the wall at various depths below the top are as follows:—4 ft. 6 in. at 5 ft.; 7 ft. at 10 ft.; 13 ft. 9 in. at 20 ft.; 21 ft. at 30 ft.; 29 ft. at 40 ft.; 38 ft. at 50 ft.; and 48 ft. 3 in. at 60 ft. The lines of resultant pressures, with reservoir full and empty, fall well within the middle third of the section.

The outlet works comprise a valve tower projecting from the upstream face of the dam at the deepest section and 12 in. outlet and scour pipes. Provision is made in the valve tower for drawing water from depths of 24 ft., 37 ft., and 50 ft., below the top of the wall. The water area with reservoir full is about 42 acres. The greatest depth of overflow observed over the bywash since the construction of the dam was 8 in. on 19th July, 1926, when the rainfall was 140 points for the day.

The works constructed in conjunction with the dam in 1890-1891 included a 12 in. c.i. pipe therefrom to Mt. Eliza, Perth, a length of 16 miles 26 chains (Fig. 2), a service reservoir of 784,000 gallons at Mt. Eliza, and 31 miles of reticulation mains. In 1897, it was found necessary to increase the supply and a second main was laid from a point on the original 12 in. main 1 mile 66 chains from Victoria Reservoir to Mt. Eliza. This new main comprised 8 miles 55 chains of 21 in. steel rivetted pipes, 3 miles 25 chains of 18 in. c.i. pipes, and 2 miles 40 chains of 20 in. c.i. pipes.

Investigations for providing additional sources for supply to meet increasing requirements resulted in sinking the first artesian bore for the City Water Supply in 1897. From that time till 1921, when the last artesian bore was sunk, the in-

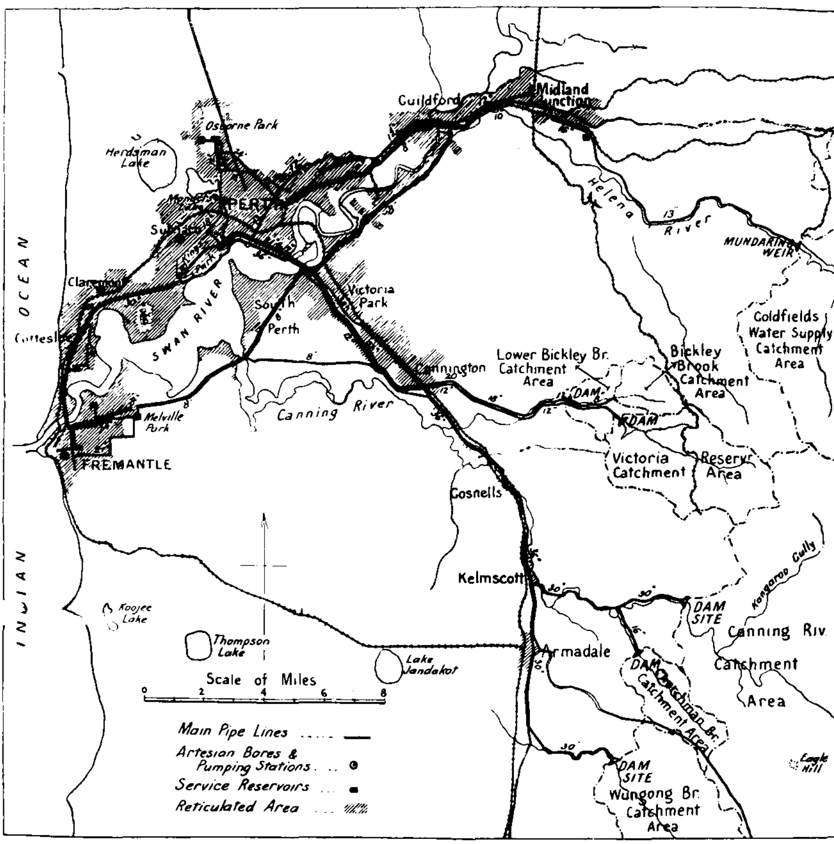



Fig. 2.

creasing requirements not only of the city but the whole metropolitan area were met for the most part from the artesian source.

In 1906, a 13 in. c.i. main was laid from Mundaring Reservoir to supply Midland Junction and Guildford. This main has since assisted the water supply of the metropolitan area to the extent of from 500,000 to 1,000,000 gallons per day. The reticulation systems of Midland and Guildford are connected to the Perth System by means of two 8 in. c.i. mains and one 12 in. c.i. main, one 8 in. main being laid south of the Swan River and the other 2 mains on the northern side.

In 1921, a concrete arched dam was built on Bickley Brook, forming a reservoir of 23,350,000 gallons capacity to conserve the overflow from Victoria Reservoir. The dam has a maximum height of 43 ft. from foundation and a length of 629 ft. The central portion is arched with a radius of 320 ft. There is a bywash 60 ft. wide at the north end. A 12 in. outlet pipe connects with the original 12 in. main from Victoria Reservoir and serves to supply the districts traversed by this main to the city.

## *Artesian Supplies.*

Table I. gives particulars of artesian bores sunk for the purpose of the Metropolitan Water Supply.

The quantity of water drawn from the artesian bores has increased gradually year by year with the demand, and as additional bores were sunk, up to a maximum of 1,881 million gallons for the year ended 30th June, 1924, and a maximum month's supply of 311 million gallons in January, 1926. The principal centre from which the artesian supply is drawn is Leederville, where a pumping station (Loftus St.) is provided capable of delivering $5\frac{3}{4}$ million gallons per day to the service reservoirs at Mt. Eliza. Four bores discharge into the suction sump at this station, viz. :—

| Bore | Max. discharge gallons per day |
|---|---|
| Loftus St. No. 1 | 1,600,000 |
| ,, No. 2 | 1,600,000 |
| Redan St. | 1,000,000 |
| Regent St. | 2,000,000 |
| TOTAL | 6,200,000 |

## TABLE N° I
## ARTESIAN BORES

| Name of Bore | Dia of Casing | Depth Feet | Date Sunk | Original Maximum Pressure lbs per Sq inch | Original Flow in Gallons per Day | Temp °Fah | CHEMICAL ANALYSES (Grains per Gallon) — Chlorides: Sodium | Chlorides: Magnesium | Carbonates: Calcium | Carbonates: Sodium | Carbonates: Magnesium | Carbonates: Iron | Sulphates: Calcium | Sulphates: Sodium | Sulphates: Magnesium | Sulphates: Potassium | Nitrate of Sodium | Silica | Iron and Aluminium Oxides | Total Solids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Loftus St N° 1 | 10" | 1001 | 1907 | 18 | 1 870 000 | 92 | 25 87 | - | 66 | 13 36 | 87 | — | 19 | 2 08 | 13 | — | — | 1 08 | 16 | 44·40 |
| - - N° 1 | 8" | 1939 | 1912 | 28 | 1 400·000 | 102 | 41 52 | — | 3 92 | 5 55 | 2 00 | — | — | 2 62 | — | — | — | 69 | Trace | 56·30 |
| - - N° 2 | 10" | 2097 | 1911 | 30 | 2 400 000 | 106 | 71 61 | — | 6 02 | 7 77 | 3 10 | — | — | 4 66 | — | — | — | 1 54 | Trace | 94 70 |
| Redan Street | {9" {6" | 1207 1813 | 1904 | 21 | 960 000 | 101 | 31 29 | — | 1 22 | 8 32 | 83 | — | — | 2·89 | — | — | — | 1 09 | — | 45 64 |
| Regent Street | 10 | 1232 | 1917 | 24 | 2 600 000 | 89 | 29 34 | — | 1 92 | 7 92 | 92 | — | — | 3 00 | — | — | — | 1 02 | — | 44 12 |
| Robert Street | 10 | 681 | 1920 | 16 | 1 250·000 | 76 | 14 28 | — | 3 99 | | 2 10 | 42 | — | 21 | 35 | — | — | 1·19 | 21 | 24 36 |
| Hector Street | 12" | 762 | 1921 | 16 | 1 800 000 | 81 | 38 36 | 73 | 1 68 | | 4 41 | — | 3 09 | — | 34 | — | — | 1 23 | 24 | 50 08 |
| King Edward St | 10 | 568 | 1921 | 12 | 1,480 000 | 75 | 30 75 | 3 92 | 80 | | 1 15 | — | 4 15 | — | — | — | — | 1·32 | ·06 | 42 75 |
| Subiaco | {6 {5 | 643 876 | 1898 | Sub Artesian | — | 95 | 23 92 | — | 95 | 12 98 | 1 16 | — | — | 2 10 | — | — | — | 70 | — | 42 40 |
| Claremont N° 1 | 5 | 1506 | 1903 | 30 | 480 000 | 100 | 56 98 | — | 2 80 | 5 95 | 3 85 | — | — | 2 59 | — | 63 | 28 | ·49 | 07 | 13 64 |
| Claremont N° 2 | {10 {8 | 1478 1943 | 1906 | 35 | 1 000 000 | 104 | 42 35 | — | 2 45 | 10 36 | 2 66 | — | — | 1 68 | — | 63 | 26 | ·49 | ·28 | 61 18 |
| Fremantle N° 1 | 6 | 456 | 1902 | 13 | 99 000 | 80 | 51 81 | 15 | 2 48 | Trace | 2 41 | — | ·95 | — | ·32 | — | — | 1·33 | 18 | 62 63 |
| Fremantle N° 2 | 4 | 1322 | 1902 | 13 | 1 070 000 | 87 | 60 52 | — | 2 83 | 1 70 | 2 25 | — | — | 6 93 | — | — | — | 70 | Trace | 72 93 |

Two artesian bores at Fremantle have been drawn on continuously from the time they were sunk in 1902 till April, 1926, the quantity pumped varying with requirements. For the year 1925-1926 the quantity varied from a minimum of 820,000 gallons per day during August to a maximum of 2,800,000 gallons per day during January. The bores at Perth and Claremont have been used for the most part for summer supply only—the bores being shut down for several months in the winter when sufficient water was available from the hills sources.

In all cases where the bores are allowed to flow freely, the static pressure falls gradually. Thus, Loftus St. No. 1 bore 8 in., when shut down for the winter increases in pressure to 28 lbs. per sq. inch, and during the pumping season gradually decreases to about 20 lbs. per square inch, the flow from the bore at the same time decreasing from 1,250,000 gals. per day at the beginning of the pumping season to 850,000 gals. per day at the end. The discharge from the Regent St. bore decreases during the pumping season from 2,000,000 gals. per day to about 600,000 gallons per day and the pressure at the same time decreases from 23 lbs. per square inch to 2 lbs.

The rise and fall of the static pressure consequent on the varying quantities of water drawn from the bores takes place now apparently just as it did when the artesian basins were first tapped—the pressure rising as a rule substantially to the original static-pressure after the bores have been shut down for several months (Fig. 3). This indicates that the artesian supply is being continually replenished and there is no indication of exhaustion of the supply. The fall of the pressure indicates too, that no great increase in the supply of water from the bores can be expected by sinking additional bores near existing bores to the same artesian horizon.

There is no direct evidence available to show to what extent or distance the fall in pressure at a bore affects the pressure in the artesian horizon surrounding the bore since there is no instance where it is definitely known that two bores tap the same artesian supply. The group of bores supplying Loftus Street pumping station are capable of delivering, in the early part of the pumping season, about 5 million gallons per day flowing freely, and after 3 or 4 months' continuous flow the quantity discharged falls to about 3¾ million gallons per day and would apparently keep on indefinitely at this rate. Some slight increase in the flow might be expected from sinking further bores in the same locality from the same horizons and a material increase would probably be secured by bores sunk to

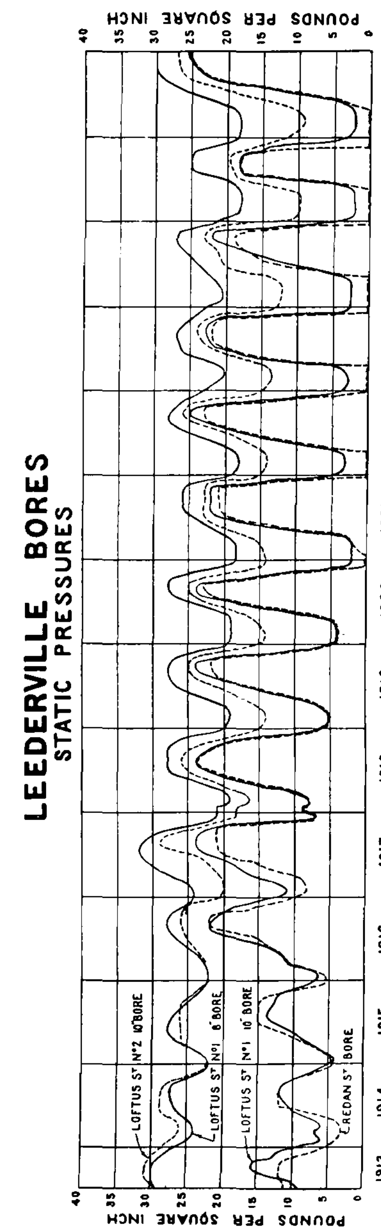

LEEDERVILLE BORES
STATIC PRESSURES
POUNDS PER SQUARE INCH
LOFTUS ST N°2 10" BORE
LOFTUS ST N°1 8" BORE
LOFTUS ST N°1 10" BORE
REDAN ST BORE
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
40
35
30
25
20
15
10
5
0

*Fig.* 3.

the same horizons at distances of half a mile or more from an existing bore.

The water from the bores is invariably clear and free from bacteria. Typical analyses are given in Table I.

The waters issuing from the three bores at Osborne Park are all perfectly clear but carry comparatively large amounts of iron in solution and, on exposure to the air, quickly become cloudy and brown with oxide of iron. These waters are accordingly aerated to oxidise the iron by streaming over weirs at the bore heads, and after passing through a settling tank, where much of the oxide is deposited, they are filtered through slow sand filters. The result is a water of good quality.

The depths of the bores from which water is used varies from 456 feet to 2,097 feet. The depth from which the water is drawn is found to have a direct influence on the pressure, temperature and salinity of the water—each of these increasing with the depth as shown in following typical examples :—

| Bore | Depth feet | Static Pressure lbs. per sq. in. | Temperature Deg. F. | Solids (Grs. per gallon) |
|---|---|---|---|---|
| Loftus St. No. 2 ... | 2097 | 30 | 105 | 90 |
| „ No. 1—8 in. | 1925 | 28 | 102 | 56 |
| Redan St. ... ... | 1812 | 22 | 100 | 47 |
| Regent St. ... ... | 1234 | 24 | 89 | 44 |
| Loftus St. No. 1—10 in. | 1001 | 18 | 92 | 44 |
| Roberts St. ... ... | 681 | 14 | 76 | 25 |

The water pumped from Loftus St., when the maximum quantity is being pumped, reaches the service reservoirs at Mt. Eliza at a temperature of about 106°F. It is there cooled by passing through shallow basins and streaming over weirs and through perforated trays before entering the service reservoirs. The maximum temperature of the water drawn from the service reservoirs at Mt. Eliza during midsummer months, when large quantities of bore water were used, was about 95°F. Cooling treatment is applied also to water pumped from the Claremont Bores. The waters from the bores at Fremantle, Subiaco and Osborne Park do not require treatment for cooling.

The warmth of the water from the bores at Loftus Street and at Claremont is highly favourable to the growth of algae where the water is exposed to sunlight. The smaller reservoirs at Claremont are accordingly roofed to exclude the sunlight and at Perth, where the reservoirs are not roofed, the water is treated with sulphate of copper, two lbs. per million gallons as

it flows from the rising main to the cooling basins. Roofing is thoroughly effective in preventing growths of algae but, at Perth, considerable labour is required in cleaning the cooling basins, in addition to sulphate of copper treatment, to keep the reservoirs clear of the algae.

The first artesian bore sunk for the Perth Water Supply at Wellington St., in 1897, was put out of use in January, 1919. The flow from this bore was originally 270,000 gals. per day. In July, 1918, the bore showed a considerable diminution of flow and continued to give a low discharge till October when the discharge increased to approximately the original flow. The discharge then again gradually decreased. Sounding the bore showed an obstruction at about 200 feet depth and samples of the obstruction brought up by fishing tools consisted of corroded iron including fragments of screw threads from the joints of the casing. Owing to the bore being situated within a large brick building it was impracticable to reline it. The flow was stopped by forcing cement grout down the bore through a connection made to the bore head, water under pressure from the town supply being used. The flow of the bore was thus completely stopped at its source, the bore head was removed and the bore filled in with a mixture of clay, cement and broken stone dropped down the bore hole in balls and rammed to within a few feet of the top which was filled with cement concrete.

Claremont No. 2 bore completed in March, 1906, developed a leak at the borehead in February, 1919. Repairs were effected by filling the annular space between the 10 in. inner casing and 12 in. casing with cast iron turnings and sal ammoniac for a depth of 40 feet and the space between the 12 in. and outer 14 in. casing with similar material to a depth of 86 feet.

In June, 1916, the water from No. 1 bore 10 in. (Fig. 4) Loftus Street, showed a change in quality from a salinity of 30 grains sodium chloride to 72 grains per gallon and the static pressure increased. At the same time the static pressure in No. 2 bore showed a slight decrease. No. 1 bore 10 in. draws water from a depth of 912 feet. Inside this 10 in. casing is an 8 in. casing that goes down to a depth of 1,873 feet. No. 2 bore is situtated only 135 feet north of No. 1 bore and has a 10 in. casing to a depth of 2,097 feet. (Fig. 4). Originally the water from the 10 in. casing of No. 1 bore had a salinity of 30 grs. sodium chloride per gallon, that from the 8 in. casing 42 grains and from No. 2 bore 72 grains per gallon and the respective pressures were 18, 28 and 30 lbs. per sq. inch. It is apparent that the change in the quality of the water from the 10 in. casing of No. 1 bore

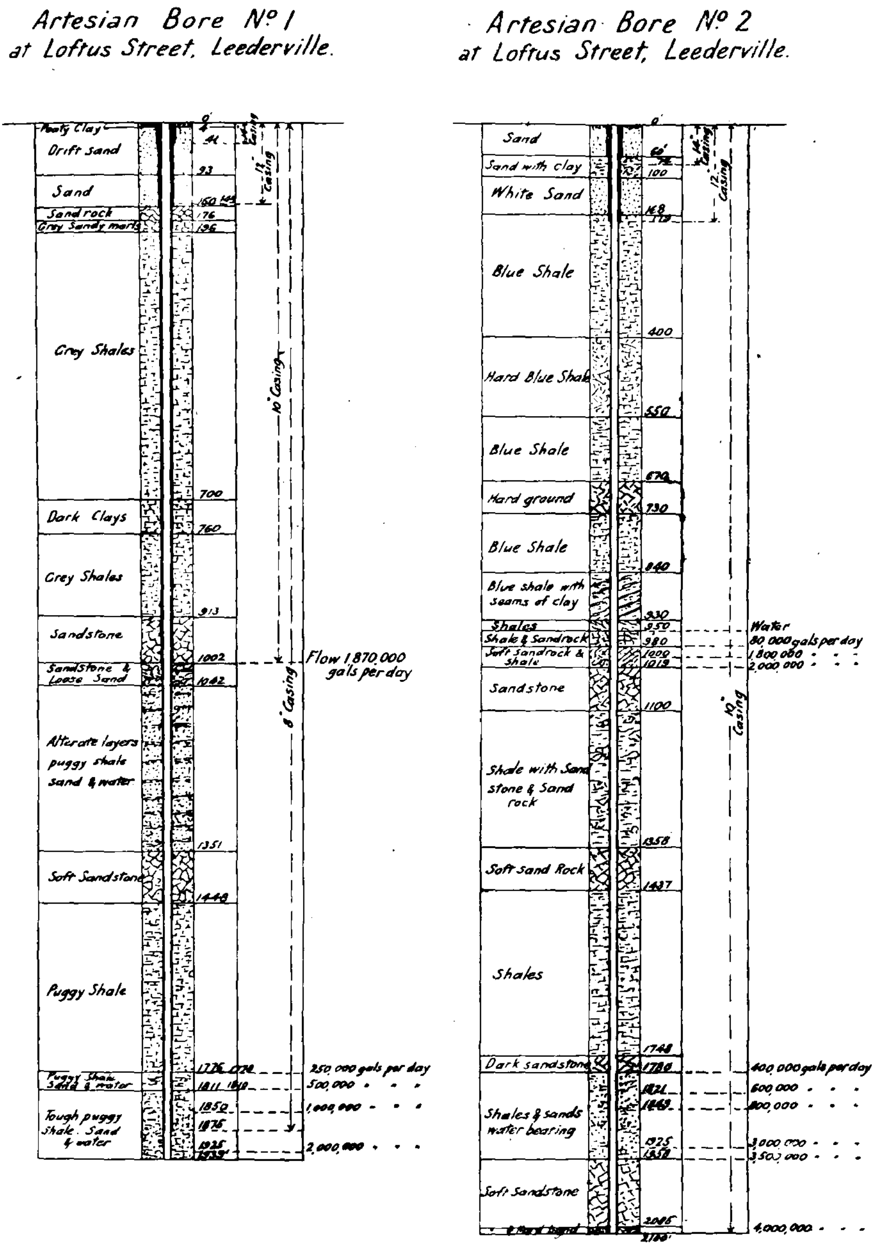

Artesian Bore No. 1
at Loftus Street, Leederville.
Drift Sand
Sand
Sandrock
Grey Shales
Dark Clays
Grey Shales
Sandstone
Alternate layers puggy shale sand & water
Soft Sandstone
Puggy Shale
Tough puggy shale. Sand & water
10" Casing
8" Casing
Flow 1,870,000 gals per day
250,000 gals per day
500,000
1,000,000
2,000,000
Artesian Bore No. 2
at Loftus Street, Leederville.
Sand
Sand with clay
White Sand
Blue Shale
Hard Blue Shale
Blue Shale
Hard ground
Blue Shale
Blue shale with seams of clay
Shales
Shale & Sandrock
Sandstone
Shale with Sandstone & Sand rock
Soft Sand Rock
Shales
Dark sandstone
Shales & sands water bearing
Soft Sandstone
12" Casing
10" Casing
Water
80,000 gals per day
1,800,000
2,000,000
400,000 gals per day
600,000
800,000
3,000,000
3,500,000
4,000,000

Fig. 4.

in June, 1916, was due to the escape of water from No. 2 bore into the strata from which the former was supplied. The quality of the water that has since flowed from the No. 1-10 in. bore continues the same as from the No. 2 bore. The escape of the water from No. 2 bore is probably due to the water finding its way up outside the steel casing to the 900 ft. level from which the No. 2-10 in. bore draws its supply. There has been no appreciable change in behaviour of either bore since 1916.

In June, 1923, No. 1 bore at Fremantle (depth 455 ft.) showed a heavy decrease in flow. On investigation it was found that the bore had become choked with sand and black clay 20 feet from the bottom. This was removed with a sand pump and the flow of the bore restored. About 20 cubic yards of sand and clay were removed from the bore.

For the purpose of increasing the flow from the bores to meet midsummer peak requirements, electrically driven centrifugal pumps have been fitted to the discharge pipes from several of the bores. In this way the discharges can be largely increased for short periods at comparatively low cost both for plant and operation. The bore at Subiaco is sub-artesian. The water is raised to the surface by means of an air lift. Air under pressure of 80 lbs. per sq. inch is supplied by an electrically-driven air compressor and forced down an air pipe in the bore to a depth of 165 ft. An air compressor is provided at Robert St. Pumping Station to supply air for air lift equipment at the bore at that station to increase the flow when required.

### *Pumping Plants.*

The pumping plant at Loftus Street consists of four pumps of the duplex triple expansion surface condensing type. Three of these are Worthington Pumps and one made by Thompson of Castlemaine, Victoria. One of the Worthington Pumps has a capacity of 100,000 gallons per hour and the other two 30,000 gallons per hour each. The capacity of the Thompson Pump is 80,000 gallons per hour. Steam is supplied by two Stirling boilers fitted with chain grates.

Fremantle Pumping Station is equipped with two Worthington triple expansion vertical direct-acting surface condensing pumps, each having a capacity of 40,500 gallons per hour, and one electrically driven 2-stage Cameron centrifugal pump capable of delivering 100,000 gals. per hour to the service reservoirs at Melville Park, *i.e.*, against a head of 200 feet. The steam boilers at this station are 4 Babcock and Wilcox boilers, burning wood fuel.

Claremont Pumping Station has one Worthington triple expansion horizontal duplex surface condensing pump with a capacity of 25,000 gallons per hour, and one duplex compound direct acting Gardner pump with a capacity of 12,000 gallons per hour. Steam is supplied by three Babcock and Wilcox boilers, burning wood fuel. At the Subiaco bore, in addition to air compressor already mentioned, there is an electrically driven 2-stage Kelly & Lewis high lift centrifugal pump capable of delivering 14,000 gals. per hour, direct into the reticulation pipes.

At Osborne Park, there is an electrically-driven 2-stage Cameron centrifugal pump capable of delivering 100,000 gals. per hour against a head of 200 feet. This plant pumps the water from the three bores at Roberts St., Hector St., and King Edward St., to the service reservoirs at Osborne Park.

Three boosting pumping plants are in use. The largest, at Alfred Cove, Melville Park, serves to assist the 8 in. main along Canning Road to deliver Hills water to Fremantle. The station is equipped with two sets of electrically-operated 5-stage centrifugal pumps each capable of delivering 16,000 gals. per hour against a head of 280 feet. There is a small electrically-driven boosting pump on Wanneroo Road, Osborne Park, capable of delivering 900 gals. per hour against a head of 90 feet for the purpose of maintaining the water supply on high areas in the locality. A storage tank of 6,000 gals. capacity is provided on one of the adjoining hills and the pump is started and stopped automatically by the fall and rise of the pressure in the main at the pump.

An electrically-driven 5-stage centrifugal pump to deliver 2,900 gals. per hour against a head of 300 feet is in use at Greenmount Reservoir, pumping water to a storage tank of 25,000 gals. on the York Road for the supply of the high levels in this locality. The pump is operated automatically by means of an electrical control worked by a float in the storage tank.

### *Population and Future Water Requirements.*

The population of the Perth metropolitan area, according to the census returns 1901, 1911 and 1921, and the estimated future population, assuming a continuation of rate of increase during the last census period, is given in Table II. and diagram Fig. 5. In 1901, the population was 67,431, and in 1911 it was 106,792, and in 1921 it was 154,873. The rate of increase, 1911 to 1921, was 3.787% per annum. Assuming this rate of

| Year ended 30th June. | Water Supply for Year | | | No. of Services | No. of Meters in use. | Estimated Population Supplied. | Average Daily Supply. | Average Daily Supply during Year | |
|---|---|---|---|---|---|---|---|---|---|
| | From Hills. | From Bores. | Total. | | | | | Per Service. | Per head of Population. |
| | **METROPOLITAN WATER SUPPLY** | | | | | | | | |
| | Gallons | Gallons | Gallons | | | | Gallons | Gallons | Gallons |
| 1909 | 349,467,000 | 670,954,000 | 1,020,421,000 | 19,653 | 8,713 | 80,000 | 2,795,675 | 142·26 | 34·95 |
| 1910 | 392,715,000 | 660,523,000 | 1,053,238,000 | 20,337 | 11,340 | 83,000 | 2,885,615 | 141·89 | 34·77 |
| 1911 | 414,512,000 | 752,546,000 | 1,167,058,000 | 21,267 | 12,355 | 87,000 | 3,197,410 | 150·34 | 36·75 |
| 1912 | 364,428,000 | 852,719,000 | 1,217,147,000 | 22,655 | 13,785 | 91,500 | 3,325,540 | 146·79 | 36·34 |
| 1913 | 469,211,000 | 905,960,000 | 1,375,171,000 | 24,150 | 16,188 | 100,000 | 3,767,595 | 156·37 | 37·67 |
| 1914 | 606,369,000 | 1,023,726,000 | 1,630,095,000 | 28,391 | 16,955 | 120,000 | 4,466,012 | 157·30 | 37·22 |
| 1915 | 387,074,000 | 1,358,199,000 | 1,745,273,000 | 29,721 | 18,275 | 125,400 | 4,781,570 | 160·88 | 38·13 |
| 1916 | 894,057,000 | 955,076,000 | 1,849,132,000 | 30,782 | 18,570 | 129,300 | 5,052,273 | 164·13 | 39·07 |
| 1917 | 704,251,000 | 1,160,464,000 | 1,864,715,000 | 31,698 | 19,967 | 133,131 | 5,108,794 | 161·17 | 38·38 |
| 1918 | 870,671,000 | 892,114,000 | 1,862,785,000 | 32,396 | 20,749 | 136,063 | 5,103,520 | 157·54 | 37·51 |
| 1919 | 899,194,000 | 1,276,122,000 | 2,175,316,000 | 33,196 | 20,402 | 152,700 | 5,959,770 | 179·53 | 39·03 |
| 1920 | 903,072,000 | 1,339,364,000 | 2,242,436,000 | 34,633 | 21,406 | 160,000 | 6,126,876 | 176·91 | 38·29 |
| 1921 | 889,723,000 | 1,423,705,000 | 2,313,428,000 | 35,558 | 21,333 | 165,000 | 6,338,166 | 178·25 | 38·37 |
| 1922 | 1,026,636,000 | 1,560,531,000 | 2,587,167,000 | 36,523 | 21,475 | 168,000 | 7,088,128 | 194·07 | 42·19 |
| 1923 | 1,107,067,000 | 1,596,354,000 | 2,703,421,000 | 37,876 | 21,741 | 171,000 | 7,406,633 | 195·55 | 43·31 |
| 1924 | 1,196,456,000 | 1,881,105,000 | 3,077,561,000 | 39,256 | 22,076 | 174,000 | 8,408,637 | 214·20 | 48·32 |
| 1925 | 1,085,181,000 | 1,812,011,000 | 2,897,192,000 | 40,605 | 23,379 | 178,000 | 7,937,510 | 195·48 | 44·59 |
| 1926 | 1,511,161,000 | 1,619,983,000 | 3,131,144,000 | 42,302 | 24,750 | 184,000 | 8,578,477 | 202·79 | 46·63 |
| 1931 * | | | 4,707,040,000 | 49,840 | 39,900 | 224,600 | 12,896,000 | 260·00 | 57·00 |
| 1936 * | | | 6,602,120,000 | 58,720 | 47,000 | 270,500 | 18,088,000 | 310·00 | 67·00 |
| 1941 * | | | 9,259,685,000 | 69,180 | 55,300 | 325,700 | 25,369,000 | 370·00 | 78·00 |

* Estimated

*Table II.*

increase to continue, the population to be supplied with water in 1931 will be about 225,000 and in 1941 about 325,000. The consumption of water from 1914 to 1926 and the estimated consumption for the future up to 1941 is also shown on this diagram. The average daily consumption was $4\frac{1}{2}$-million gallons per day in 1914 and since then has shown an average increase of 7 per cent. per annum. Assuming this rate of increase to continue, the quantity of water to be provided amounts to about 12-million gallons per day in 1931 and 25-million per day in 1941. The higher rate of increase in consumption 7% as compared with the rate of increase in population 3.787% is consistent with experience in other Australian capital cities, and also with the conditions likely to obtain in the Perth areas in the near future, viz., extension of the sewerage system, which at present serves only 42% of the population, more liberal use of water for gardening and general domestic uses as standard of living and prosperity increases, and more water required for industrial purposes.

To meet these rapidly increasing requirements, recourse must necessarily be made to the supplies available from the catchment area in the Hills.

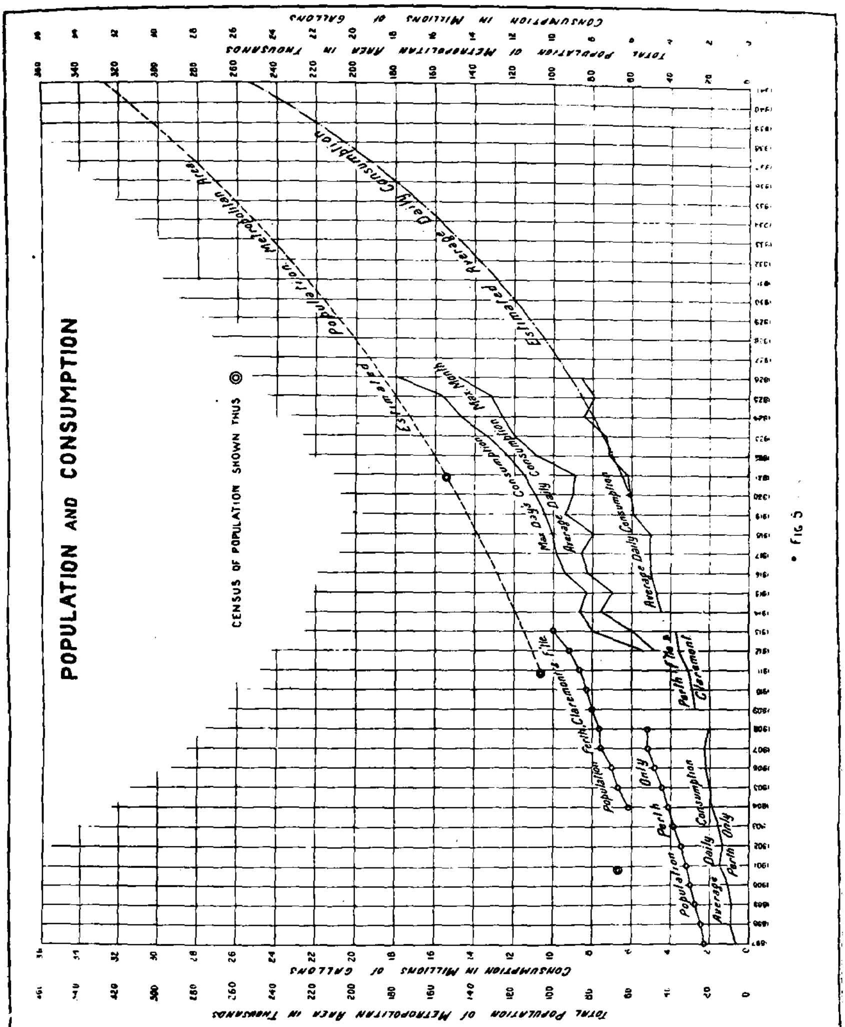



FIG. 5

## *Supplies Available from Hills.*

Gaugings of the Canning River were commenced in 1897 and of other streams within economic reach of Perth in 1910, as shown in Tables III. to VI. To supplement this data and to appreciate its value for purposes of design of water conservation works, there are also available rainfall records at Perth from 1874, Victoria Reservoir from 1892, Mundaring Weir from

| NAME OF RIVER OR STREAM | CANNING RIVER AT Nº 1 WEIR SITE | | KANGAROO GULLY | | TURTLE BROOK | | CHURCHMAN BROOK | | WUNGONG BROOK | | SERPENTINE RIVER | | MUNDAY BROOK VICTORIA RESERVOIR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AREA OF CATCHMENT | 290 SQ MILES | | 27.5 SQ MILES | | 2.13 SQ MILES | | 8 SQ MILES | | 50 SQ MILES | | 300 SQ MILES | | 14.5 SQ MILES | |
| YEAR | DISCHARGE | PER CENT RUN OFF | DISCHARGE | PER CENT RUN OFF | DISCHARGE | PER CENT RUN OFF | DISCHARGE | PER CENT RUN OFF | DISCHARGE | PER CENT RUN OFF | DISCHARGE | PER CENT RUN OFF | DISCHARGE | PER CENT RUN OFF |
| 1897 | 775558 | 0·74 | NOT GAUGED | | NOT GAUGED | | NOT GAUGED | | NOT GAUGED | | NOT GAUGED | | NOT GAUGED | |
| 1898 | 3,028,406 | 2·32 | D° | | D° | | D° | | D° | | D° | | D° | |
| 1899 | NOT GAUGED | | D° | | D° | | D° | | D° | | D° | | D° | |
| 1900 | D° | | D° | | D° | | D° | | D° | | D° | | D° | |
| 1901 | 2,014,143 | 1·85 | D° | | D° | | D° | | D° | | D° | | D° | |
| 1902 | 713,661 | 0·74 | D° | | D° | | D° | | D° | | D° | | D° | |
| 1903 | 4,463,387 | 3·37 | D° | | D° | | D° | | D° | | D° | | D° | |
| 1904 | NOT GAUGED | | D° | | D° | | D° | | D° | | D° | | D° | |
| 1905 | D° | | D° | | D° | | D° | | D° | | D° | | D° | |
| 1906 | D° | | D° | | D° | | D° | | D° | | D° | | D° | |
| 1907 | 12,597 265 | 7·86 | D° | | D° | | D° | | D° | | D° | | D° | |
| 1908 | 2 634 130 | 2·24 | 648,209 | 5·55 | 77270 | 5·91 | D° | | D° | | D° | | 744,815 | 11·3 |
| 1909 | 4,705,365 | 3·22 | 1,034482 | 7·03 | 102,563 | 7·40 | D° | | D° | | D° | | 930,430 | 12·0 |
| 1910 | 12 685,686 | 7·43 | 1909,523 | 11·20 | 140,839 | 8·70 | 680793 | NOT COMPLETE | D° | | D° | | 1488,037 | 16·3 |
| 1911 | 1,649,931 | 1·54 | 524,248 | 4·56 | 71,765 | 6·50 | 436,801 | 11·23 | 2,062,303 | 9·4 | 5,608 285 | NOT COMPLETE | 683824 | 9·1 |
| 1912 | 5 192,685 | 3·68 | 867502 | 6·17 | 95,071 | 7·12 | 437,383 | 9·70 | 3 138,637 | 12·3 | 11,811,678 | 8·80 | 649,485 | 8·7 |
| 1913 | 4 852,498 | 3·11 | 752,817 | 5·00 | 78,730 | 5·51 | 494,613 | 9·77 | 2,967,324 | 8·9 | 10,504,764 | 7·16 | 640,928 | 7·7 |
| 1914 | 87 889 | 0·11 | 47,882 | 0·63 | 29,595 | ·41 | 206,412 | 7·63 | 518,307 | 2·7 | 1,389,306 | 1·79 | 109,159 | 2·7 |
| 1915 | 11,569,024 | 5·54 | 1,728,632 | 8·80 | 119,129 | 6·39 | 697,306 | 10·06 | 6,455,173 | 14·3 | 19,329,382 | 10·81 | 1,466,880 | 15·4 |
| 1916 | 4,378,273 | 2·71 | 827,544 | 5·29 | 90,470 | 6·09 | 658,359 | 12·00 | 4,299 253 | 11·9 | 11,197,758 | 8·20 | 705,726 | 9·0 |
| 1917 | 31 488,839 | 12·27 | 4,374,055 | 17·61 | 609,387 | 26·76 | 1,580,662 | 19·27 | 12,984,711 | 25·0 | 31,492,638 | 14·49 | 2,890228 | 24·8 |
| 1918 | 13,511,666 | 6·78 | 2,867,889 | 14·80 | 559,856 | 30·51 | 1,340,931 | 21·03 | 8,178,904 | 21·1 | 28,409 503 | 17·06 | 2,148,326 | 24·0 |
| 1919 | 4,342,816 | 2·80 | 762,117 | 5·19 | 168,303 | 12·09 | 795,500 | 15·47 | 3,939,117 | 12·5 | 17,560,640 | 9·45 | 991,517 | 14·0 |
| 1920 | 15 439,483 | 7·34 | 2,519,623 | 12·70 | 278,816 | 14·85 | 1,084,916 | 15·95 | 6,871,100 | 17·9 | 17,787,991 | 10·18 | 2,267,809 | 26·0 |
| 1921 | 6,856,970 | 3·43 | 1 227,850 | 6·06 | 228,194 | 11·9 | 924,729 | 14·65 | 5,193,453 | 12·5 | 17,281,201 | 9·45 | 1,488,509 | 16·2 |
| 1922 | 4,249,623 | 2·83 | 589,141 | 3·64 | 165,079 | 10·78 | 683,954 | 13·88 | 3,589,879 | 10·9 | 12,279,320 | 9·61 | 782,390 | 10·7 |
| 1923 | 23 550,000 | 11·28 | 2507,591 | 10·44 | 386,277 | 16·99 | 1,332,383 | 17·59 | 8,853,991 | 18·2 | 30 525,537 | 16·80 | 2 619,019 | 24·1 |
| 1924 | 13 429,819 | 7·17 | 1 540,338 | 7·86 | 529,118 | 28·50 | 1,098,165 | 17·91 | 7 146,586 | 16·75 | 19,208,951 | 11·71 | 1,621,461 | 20·87 |
| 1925 | 3,416,567 | 1·78 | 588,710 | 3·96 | 268,319 | 19·05 | 709,936 | 13·28 | 3 311,894 | 9·75 | 10,984 803 | 7·05 | 606,509 | 9·05 |
| 1926 | 32,581,942 | 5·66 | 4,490,048 | 16·97 | 637,110 | 20·21 | NOT GAUGED | | 15 166,061 | 26·84 | 34 236,206 | 14·54 | 2,747,337 | 20·91 |
| AVERAGE ANNUAL FLOW | 8,809,425 | 4·47 | 1,568,338 | 8·07 | 243,993 | 12·88 | 832,139 | 14·73 | 5,917 293 | 14·43 | 17,860,564 | 10·45 | 1,341,231 | 14·85 |

*Table III.—Annual Discharge in Thousands of Gallons.*

| Year | Jan | Feb | Mch | April | May | June | July | Aug. | Sep | Oct | Nov. | Dec. | Total | Flow per Sq. Mile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1908 | 6 | | | | 20 | 237 | 2,088 | 544 | 255 | 183 | 28 | 9 | 3,370 | 10·7 |
| 9 | 6 | 6 | 6 | 5 | 32 | 421 | 312 | 3,162 | 953 | 886 | 168 | 9 | 5,966 | 18·9 |
| 1910 | 6 | 3 | 3 | 6 | 166 | 964 | 5,665 | 4,091 | 2,940 | 510 | 116 | 23 | 14,493 | 46·1 |
| 11 | 6 | 3 | 3 | 12 | 24 | 108 | 431 | 1,002 | 630 | 92 | 16 | 7 | 2,334 | 7·4 |
| 12 | 3 | 3 | 3 | 3 | 18 | 14 | 1,118 | 675 | 3,336 | 912 | 68 | 7 | 6,160 | 19·6 |
| 13 | 2 | 2 | 0 | 2 | 2 | 35 | 394 | 3,697 | 1,055 | 495 | 55 | 48 | 5,787 | 18·4 |
| 14 | 4 | 3 | 3 | 4 | 4 | 16 | 91 | 48 | 22 | 6 | 6 | 3 | 210 | ·66 |
| 15 | 3 | 29 | 5 | 4 | 15 | 250 | 2,343 | 5,257 | 4,188 | 2,963 | 214 | 10 | 15,281 | 48·5 |
| 16 | 5 | 8 | 5 | 5 | 9 | 122 | 828 | 3,251 | 780 | 409 | 175 | 22 | 5,619 | 17·8 |
| 17 | 4 | 4 | 4 | 6 | 19 | 1,045 | 11,499 | 7,809 | 11,326 | 7,335 | 686 | 271 | 40,008 | 127·0 |
| 18 | 85 | 42 | 31 | 81 | 420 | 7,896 | 2,405 | 2,909 | 4,533 | 1,859 | 635 | 116 | 21,012 | 66·7 |
| 19 | 45 | 25 | 34 | 56 | 75 | 239 | 712 | 2,274 | 937 | 608 | 336 | 98 | 5,439 | 17·2 |
| 1920 | 33 | 15 | 16 | 14 | 88 | 2,501 | 3,640 | 8,746 | 2,433 | 689 | 213 | 75 | 18,463 | 58·6 |
| 21 | 57 | 20 | 19 | 24 | 308 | 729 | 2,693 | 1,613 | 1,487 | 983 | 465 | 95 | 8,493 | 26·96 |
| 22 | 41 | 26 | 22 | 26 | 112 | 212 | 1,511 | 1,823 | 778 | 388 | 124 | 83 | 5,146 | 16·33 |
| 23 | 44 | 23 | 46 | 65 | 232 | 3,037 | 3,880 | 3,078 | 12,021 | 3,590 | 517 | 171 | 26,704 | 84·77 |
| 24 | 103 | 58 | 42 | 52 | 134 | 510 | 1,149 | 4,304 | 2,960 | 4,936 | 1,226 | 219 | 15,693 | 49·81 |
| 25 | 98 | 75 | 99 | 60 | 214 | 346 | 1,355 | 734 | 671 | 547 | 126 | 62 | 4,387 | 13·92 |
| 26 | 24 | 15 | 28 | 247 | 1,942 | 2,456 | 7,944 | 5,611 | 4,177 | 4,440 | 1,568 | 414 | 28,866 | 91·66 |

*Table IV.—Canning River at No. 2 Proposed Weir Site. Catchment Area—315 Sq. Miles. Flow in millions of gallons.*

| Year | Jan | Feb | Mch. | April | May | June | July | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1911 | | | 15 | 35 | 76 | 150 | 365 | 654 | 533 | 184 | 73 | 43 | 2,128 |
| 12 | 17 | 9 | 7 | 6 | 38 | 45 | 706 | 486 | 1,382 | 698 | 161 | 63 | 3,618 |
| 13 | 20 | 10 | 9 | 11 | 13 | 116 | 349 | 1,740 | 588 | 465 | 139 | 139 | 3,599 |
| 14 | 37 | 8 | 7 | 6 | 13 | 61 | 148 | 89 | 78 | 35 | 31 | 11 | 518 |
| 15 | 6 | 5 | 8 | 9 | 25 | 202 | 1,411 | 1,758 | 1,850 | 1,347 | 458 | 152 | 7,231 |
| 16 | 58 | 43 | 20 | 18 | 44 | 155 | 821 | 1,751 | 683 | 397 | 229 | 82 | 4,299 |
| 17 | 24 | 21 | 12 | 38 | 89 | 604 | 3,497 | 2,539 | 2,393 | 2,528 | 752 | 485 | 12,985 |
| 18 | 182 | 81 | 74 | 101 | 386 | 1,613 | 802 | 1,285 | 1,512 | 1,330 | 596 | 217 | 8,179 |
| 19 | 101 | 82 | 60 | 102 | 110 | 314 | 539 | 1,328 | 499 | 476 | 218 | 110 | 3,939 |
| 1920 | 54 | 20 | 23 | 27 | 112 | 1,234 | 1,343 | 2,148 | 964 | 551 | 281 | 113 | 6,871 |
| 21 | 62 | 25 | 23 | 37 | 351 | 493 | 1,169 | 909 | 867 | 680 | 442 | 135 | 5,193 |
| 22 | 63 | 26 | 23 | 43 | 172 | 274 | 845 | 1,125 | 424 | 349 | 147 | 97 | 3,590 |
| 23 | 45 | 17 | 37 | 45 | 227 | 1,291 | 1,438 | 1,361 | 2,237 | 1,471 | 493 | 193 | 8,854 |
| 24 | 138 | 90 | 63 | 67 | 191 | 470 | 791 | 1,754 | 1,059 | 1,535 | 767 | 223 | 7,148 |
| 25 | 99 | 73 | 70 | 59 | 159 | 348 | 894 | 478 | 507 | 400 | 151 | 74 | 3,312 |
| 26 | 39 | 28 | 38 | 170 | 331 | 1,367 | 4,646 | 2,599 | 2,123 | 2,577 | 885 | 365 | 15,168 |

*Table V.—Wungong Brook. Catchment Area—50 Sq. M.*
*Flow in millions of gallons.*

| Year | Jan | Feb. | Mch | April | May | June | July | Aug | Sep | Oct | Nov. | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1910 | | | | | 32 | 59 | 192 | 142 | 139 | 58 | 35 | 24 | 681 |
| 11 | 17 | 11 | 9 | 18 | 24 | 32 | 63 | 126 | 74 | 31 | 17 | 14 | 436 |
| 12 | 7 | 6 | 7 | 6 | 15 | 18 | 88 | 53 | 132 | 66 | 25 | 14 | 437 |
| 13 | 9 | 4 | 2 | 8 | 8 | 30 | 60 | 194 | 71 | 57 | 29 | 23 | 495 |
| 14 | 9 | 6 | 7 | 7 | 12 | 33 | 46 | 27 | 19 | 12 | 19 | 9 | 206 |
| 15 | 7 | 9 | 10 | 13 | 26 | 54 | 118 | 143 | 134 | 118 | 44 | 21 | 697 |
| 16 | 19 | 27 | 21 | 20 | 29 | 51 | 101 | 175 | 73 | 60 | 52 | 29 | 658 |
| 17 | 17 | 19 | 22 | 30 | 47 | 145 | 290 | 234 | 271 | 276 | 107 | 123 | 1,581 |
| 18 | 79 | 51 | 55 | 66 | 87 | 213 | 131 | 184 | 166 | 140 | 99 | 71 | 1,341 |
| 19 | 48 | 30 | 31 | 44 | 47 | 74 | 126 | 148 | 85 | 75 | 51 | 36 | 795 |
| 1920 | 25 | 18 | 20 | 19 | 38 | 144 | 172 | 288 | 147 | 99 | 67 | 47 | 1,085 |
| 21 | 35 | 20 | 24 | 24 | 78 | 99 | 184 | 109 | 135 | 105 | 68 | 42 | 925 |
| 22 | 29 | 20 | 16 | 21 | 57 | 60 | 138 | 132 | 84 | 61 | 32 | 34 | 684 |
| 23 | 19 | 6 | 10 | 16 | 61 | 195 | 172 | 171 | 316 | 190 | 104 | 72 | 1,332 |
| 24 | 48 | 40 | 29 | 17 | 47 | 102 | 91 | 198 | 142 | 206 | 121 | 58 | 1,099 |
| 25 | 40 | 25 | 31 | 24 | 58 | 85 | 165 | 76 | 84 | 58 | 30 | 34 | 710 |
| 26 | 25 | 24 | 24 | 55 | 78 | | | | | | | | |

*Table VI.—Churchman Brook. Catchment Area—6 Sq. M.*
*Flow in millions of gallons.*

1900, Canning River No. 1 Dam Site from 1908, Churchman Brook from 1911, Serpentine River from 1912, Bannister from 1885, Wandering from 1889, and Jarrahdale from 1883, besides records from rain gauges established since 1923 in various parts of the catchment areas. A comparison of the rainfalls and off-flows for years where records of both are available shows clearly there is no simple ratio that can be adopted to derive the off-flows from the rainfalls so far as the Catchment areas in the vicinity of Perth are concerned. The off-flow from the Mundaring catchment area in 1902 was 0.2% of the rainfall, and in 1917 it was 11.4%. It is the intensity in conjunction with the total rainfall that governs the off-flow and it is possible to compare these for different years by plotting mass curves of the rainfall for each year, it being assumed that where the mass curves are closely similar the off-flows will be correspondingly close. Mass curves of rainfall in this way afford a valuable practicable means for estimating the off-flow for years for which daily rainfalls are available, but no stream

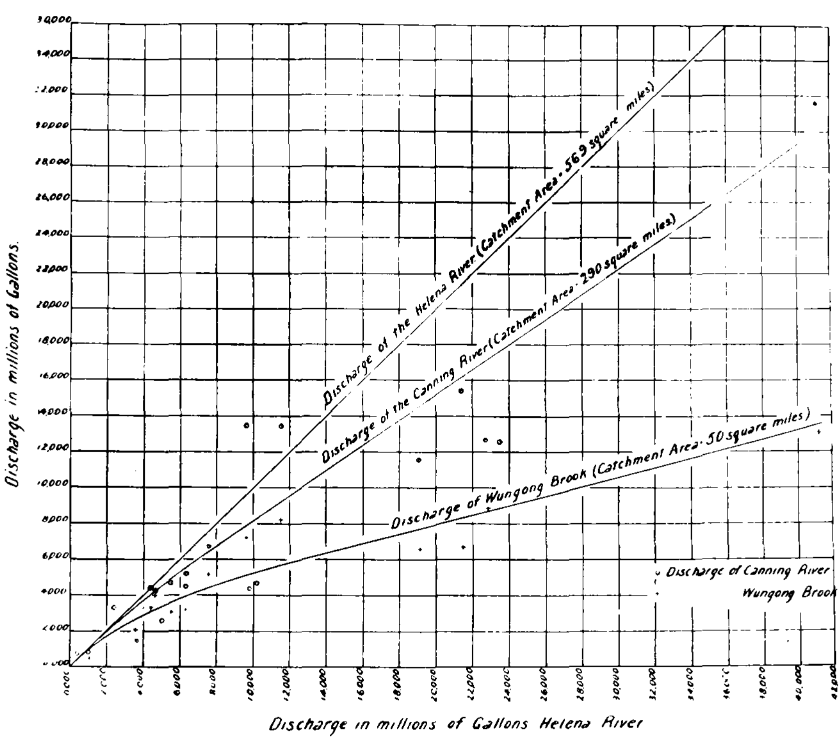



FIG. 6.

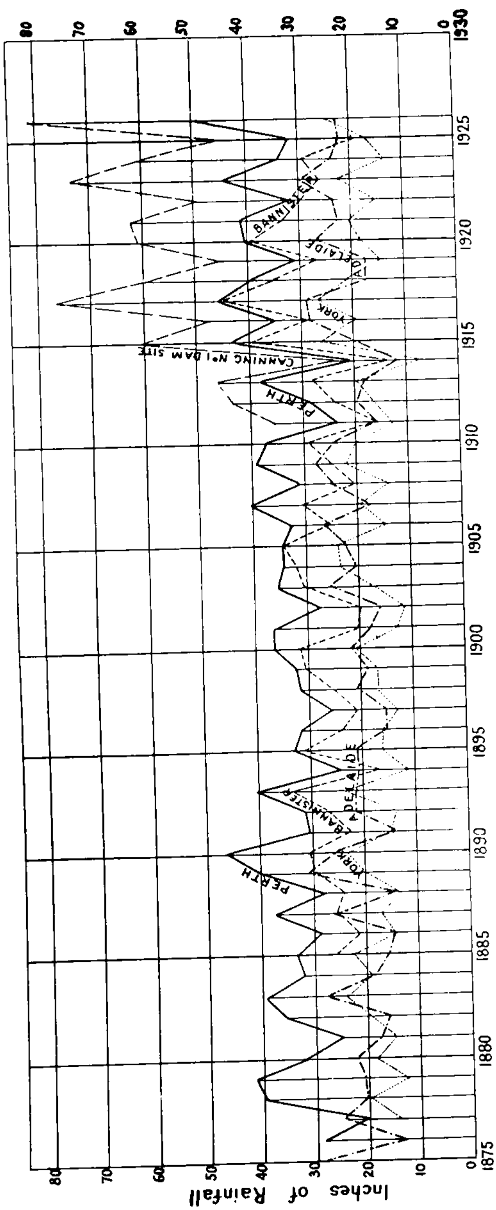
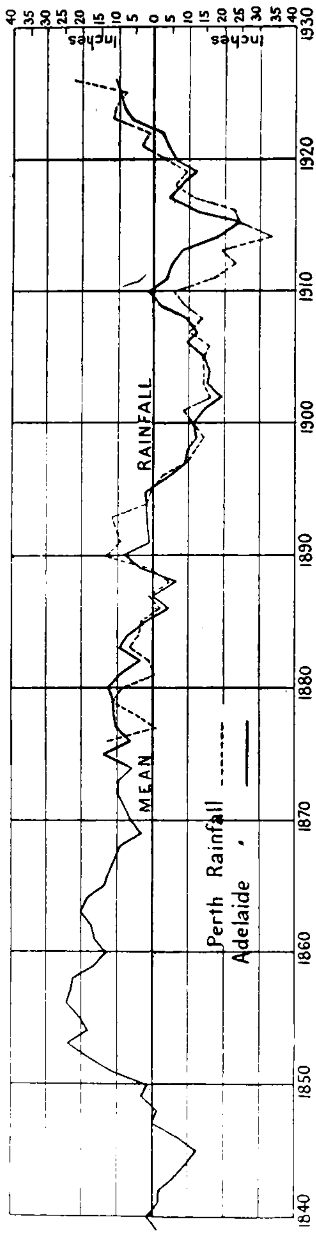

Inches of Rainfall
0
10
20
30
40
50
60
70
80
1875
1880
1885
1890
1895
1900
1905
1910
1915
1920
1925
1930
PERTH
BANNISTER
ADELAIDE
YORK
CANNING No 1 DAM SITE

*Fig. 7.*




*Mass Curves of Rainfall - Perth and Adelaide.*

*Estimated Mean Rainfall for Perth .... 34·23 Inches*

*" " " " Adelaide .. 21·05 "*

*Fig.* 8.

gaugings, by comparing the mass rainfall curves for these years with those for years during which the stream has been gauged. Another means for estimating stream flows for ungauged years is to establish a relationship between the gauged stream flows of the stream under consideration and the gauged flows of adjoining streams and from this relationship estimate the flows for other years where gaugings have been taken on these adjoining streams. (Fig. 6).

Rainfall records are of great value too in absence of stream gaugings in indicating wet and dry periods. Comparison of yearly rainfall records of Perth, York, Bannister, Canning, and Mundaring, shows a striking similarity (Fig. 7). The nearest long period record of rainfall outside the State is that of Adelaide. The yearly and mass curves of rainfall for Adelaide and Perth show again a striking similarity (Figs. 7 & 8). In both cases the period 1875 to 1902 was one of low average rainfall, 1903 to 1910 was above the average, 1911 to 1914 was much below the average, and from 1915 to date much above the average.

Perth rainfall records go back to 1874 but Adelaide's records go back to 1839. The Adelaide records show that 1841 to 1845 were low rainfall years, 1846 to 1853 was a period of very wet years, 1854 to 1864 were normal, and 1866 to 1869 dry years. The wet period, 1846 to 1853, compares closely with the wet period now being experienced since 1915. The conclusion from this is that for water supply purposes the stream flows gauged since 1915 must be considered as greatly in excess of the average and for the period 1911 to 1914 below the average. It must also be noted that there was a prolonged drought from 1894 to 1902. It is to these periods of low rainfall that particular attention must be given in considering water conservation works in connection with the Perth metropolitan area as they determine the quantity of water that can be safely depended on for the city supply. Particular importance attaches to large storage works in connection with the Perth Water Supply on account of the low rainfall and the high temperatures and evaporation experienced during the months November to March inclusive. Fig. 9 shows the average rainfall and evaporation throughout the year at Perth and Melbourne and illustrates the widely different conditions obtaining in these cities. During the months November to March, the average rainfall in Perth is 2.94 inches compared with 10.1 inches in Melbourne. For the same period the evaporations are 44 inches in Perth and 25.3 in Melbourne—*i.e.*, an excess of

41 inches evaporation over the rainfall for Perth and 15.2 inches for Melbourne.

In consequence of the dry conditions thus obtained during the summer months, the stream flows from the catchment areas usually fall away to almost negligible quantities during this period and at the same time, practically the whole of the water required to maintain the garden and lawns in the porous sandy soil of the greater part of the metropolitan area, and against the high evaporation, has to be obtained from the reticulation pipes.

The wide variations in consumption are shown in Fig. 10, which gives the average daily consumption each month for the years 1916-17, 1919-20, 1922-23, and 1925-26.

The use of the artesian source was adopted as the most economical means for securing a potable supply for the com-

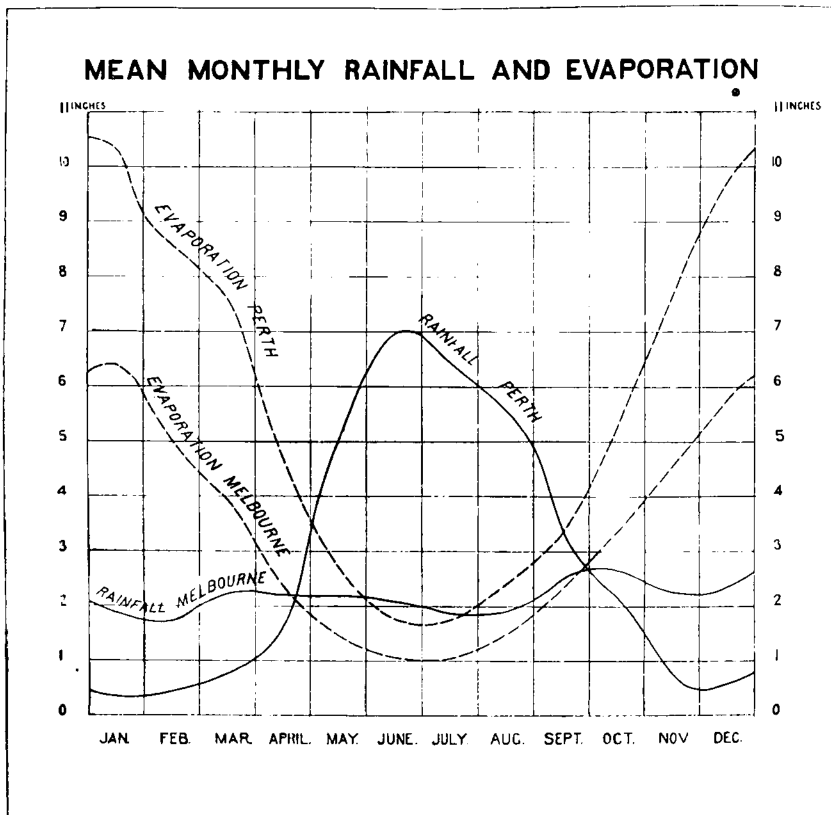



*Fig.* 9.

paratively small requirements of the time, but it has at all times been recognised and recommended by Engineers, who have been responsible for the works, that the Canning River must ultimately be the source to which the city must look for any great increase of the water supply.

In 1923, approval was given by the Government to the construction of the first works for bringing water from the Canning and Wungong Catchment areas to the city. The works so approved comprised an earthen dam on Churchman Brook, a tributary of the Canning River, and pipe lines from this dam and from diversion weirs on the Canning River and Wungong Brook to the Main Service Reservoir at Mt. Eliza.

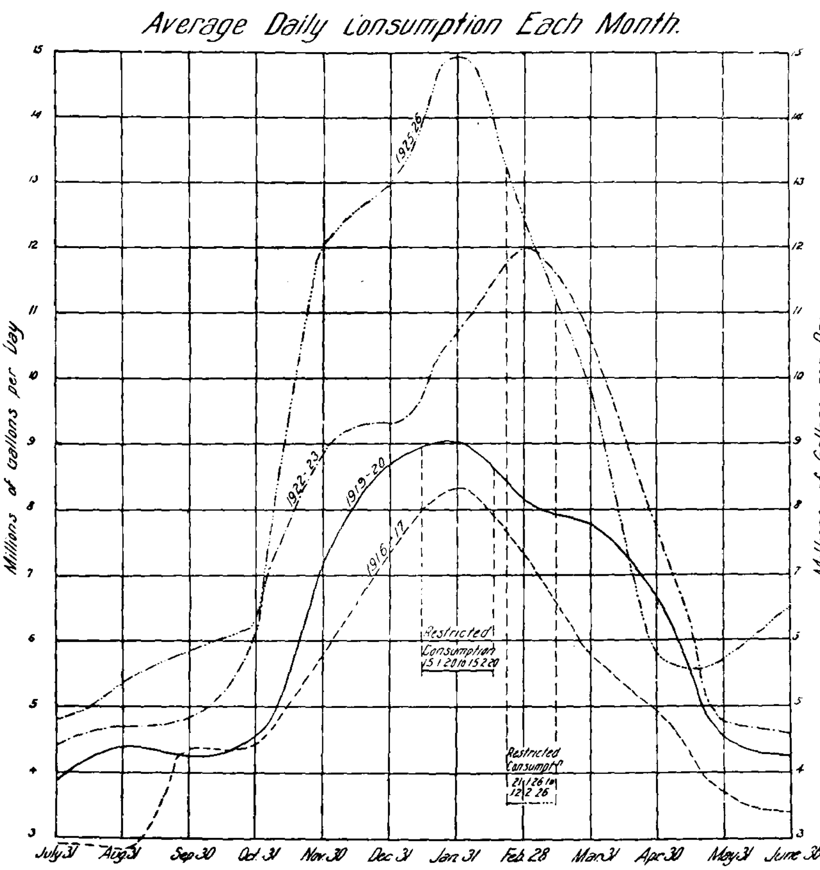



*Fig.* 10.

These works form portions of a larger scheme involving the construction of large storage reservoirs on the Canning River and Wungong Brook, and their construction enables immediate benefit to be secured to the city water supply pending the construction of the large dams which must necessarily occupy some years. The construction of the pipe lines mentioned was commenced in August, 1924, and completed to Mt. Eliza in February, 1926. Water was supplied to a portion of the city from Churchman Brook in November, 1925, from the Canning in December, 1925, and from Wungong in February, 1926. The effect of these works has been very great during the past year as they sufficed to maintain the city supply from April to the end of December without the use of water from the artesian bores.

### *New Hills Mains.*

The pipe line (Figs. 2 & 11) comprise :—

| | Miles | Chains |
|---|---|---|
| 30 in. x $\frac{3}{8}$ in. pipes, Wungong Diversion Weir to Kelmscott | 8 | 35 |
| 30 in. x $^5/_{16}$ in. pipes, Canning Diversion Weir to Kelmscott | 5 | 60 |
| 16 in. x $^3/_{16}$ in. pipes, Churchman Dam to 30 in. main Canning River ... ... ... ... ... | 1 | 61 |
| 36 in. x $\frac{3}{8}$ in. pipes, Kelmscott to Swan River ... | 13 | 66 |
| 36 in. x $^5/_{16}$ in. pipes, Swan River to Mt. Eliza ... | 3 | 9 |

The pipes in all cases are steel lock-bar pipes, 28 ft. in length, manufactured by Messrs. Mephan Ferguson. The 16 in. pipes were made in Adelaide. All the rest were made at Maylands, near Perth. All pipes were coated by dipping in a bath of tar-bitumen mixture and were wrapped with hessian. The joints are made with joint rings, with through lead joints, hand caulked. The pipes were transported some by rail to Kelmscott and Armadale but for the most part by motor trucks from the manufacturers' works as far as made roads were available and thence by horse drawn jinkers along tracks formed for the purpose to the pipe lines. The steel plates and bars used for the pipes were made in England. The steel for the plates had a tensile strength of 22 to 29 tons per sq. inch and elongation 20 to 30% in 8 in. The steel for locking bars and joint rings had a tensile strength of from 23 to 26 tons per square inch and elongation 28 to 39% in 10 in. The stop valves used in the pipe mains were, with the exception of one 21 in. stop valve of local manufacture, imported from England. They include six 36 in. stop valves, two 30 in. stop valves, five 21 in.

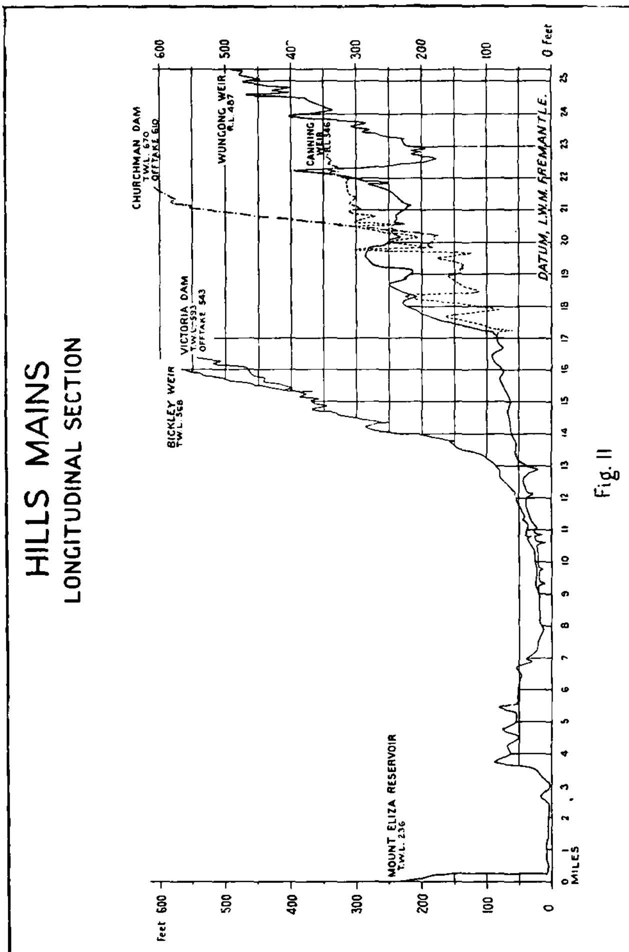



Fig. 11

stop valves, and one 15 in. pressure reducing needle valve. All the stop valves are provided with suitable concrete pits for access to valve covers and for anchorage. The pipe mains are fitted with air valves at high points, and 6 in. and 12 in. scour valves at convenient places for emptying the mains. Changes in direction in the main are provided for in some cases by special bends of the required angle and in others by laying the pipes on curves. The maximum angle used at pipe joints on curves is 4°. The smallest radius of curve used was 130 feet. In this case the pipes were cut in lengths of 9 ft. 4 in., with ends splayed to give a close joint all round the circum-

ference. All cutting was done on the spot with oxy-acetylene blow pipe. The pipes are laid in the ground with normally 12 in. to 18 in. of earth covering.

It was originally intended to use steel castings for all bends required and a contract was let accordingly. Difficulty was, however, experienced in the manufacture of these large steel castings and as the consequent delay was hindering the completion of the main, arrangements were made for making some of the required bends by cutting short pieces of the steel pipes to the required angles with the oxy-acetylene torch and welding them together with an electric arc. By this means 30° bends were made in 2 sections, and 45° and 60° bends in 3 sections. The cost of a 45° bend 36 in. dia. made in this way was £22 as against £37 for cast steel bend. All bends used in the mains were securely anchored by concrete bolsters. The crossing of the Perth-Bunbury Railway was effected by constructing a reinforced concrete culvert under the railway with internal dimensions 11 ft. 4 in. x 5 ft. 2 in. x 58 ft. 4 in. in length, large enough to accommodate the 36 in. pipe now laid and an additional pipe of the same diameter to be laid at a future date.

The construction of the pipe lines required 9 bridges over the Canning River, 4 over the Wungong and one over the Swan River. The Bridges over the Canning and Wungong comprised for the most part solid concrete piers on rock foundation spaced 17 ft., 17 ft. and 22 ft. centres so that alternate pipes were supported on one and two piers respectively, the piers in the latter case being kept 3 feet from the joints to allow for caulking. Where rock or other suitable foundation for concrete piers were not obtainable, as in the bed of the Canning River at Kelmscott and Gosnells, jarrah piles were driven.

Over the Swan River—¾ miles in length—the pipes are carried on piles for a length of 1,626 feet and on earth embankment for 2,339 ft. The piers and embankments at this crossing have been made wide enough to accommodate 3 additional water mains for future requirements and there is a steel truss with 40 ft. span over a navigation water way.

The piers and bridges over the Canning River have been made wide enough to take a second main.

As the 36 in. pipe main approaches its terminus at Mt. Eliza, it has to rise from the level of the river to the top of the steep slopes of the mount which rise 140 ft. in a horizontal distance of 217 ft. The slopes are of fine red sand. The ascent of the pipes was effected by tunnelling into the hillside on a

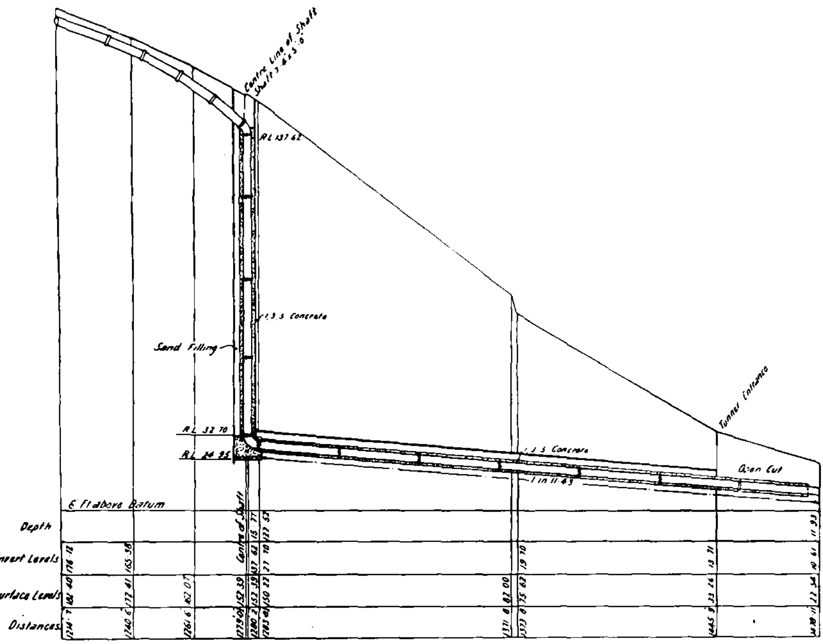



*Fig.* 12.

rising grade of 1 in 11.43 for a length of 163 ft., and then rising vertically 110 ft. in a shaft to a point where the pipes could be laid in a trench (Fig. 12). In view of the difficulty of renewal in this section of the work, the pipes were lined with 1 in. cement and sand mortar with wire netting re-inforcement and surrounded with concrete. Flanged joints with rubber insertion were used in the tunnel and shaft—the flanges being cast steel rivetted and electrically welded to the pipes, and all joints were carefully examined inside and pointed up with mortar.

At each of the diversion wiers, the entrance to the pipe is from a concrete chamber, 13 ft. 3 in. x 3 ft. 7 in. along one side of which are fitted brass wire screens through which the whole of the water diverted to the pipe must pass. The screens are in duplicate. Each screen is 4 ft. 2 in. x 3 ft. 3 in., fitted in guides for convenience of removal and cleaning. The total area of the screen is 32 sq. ft. They are made of 20 gauge wire with 8 wires per inch.

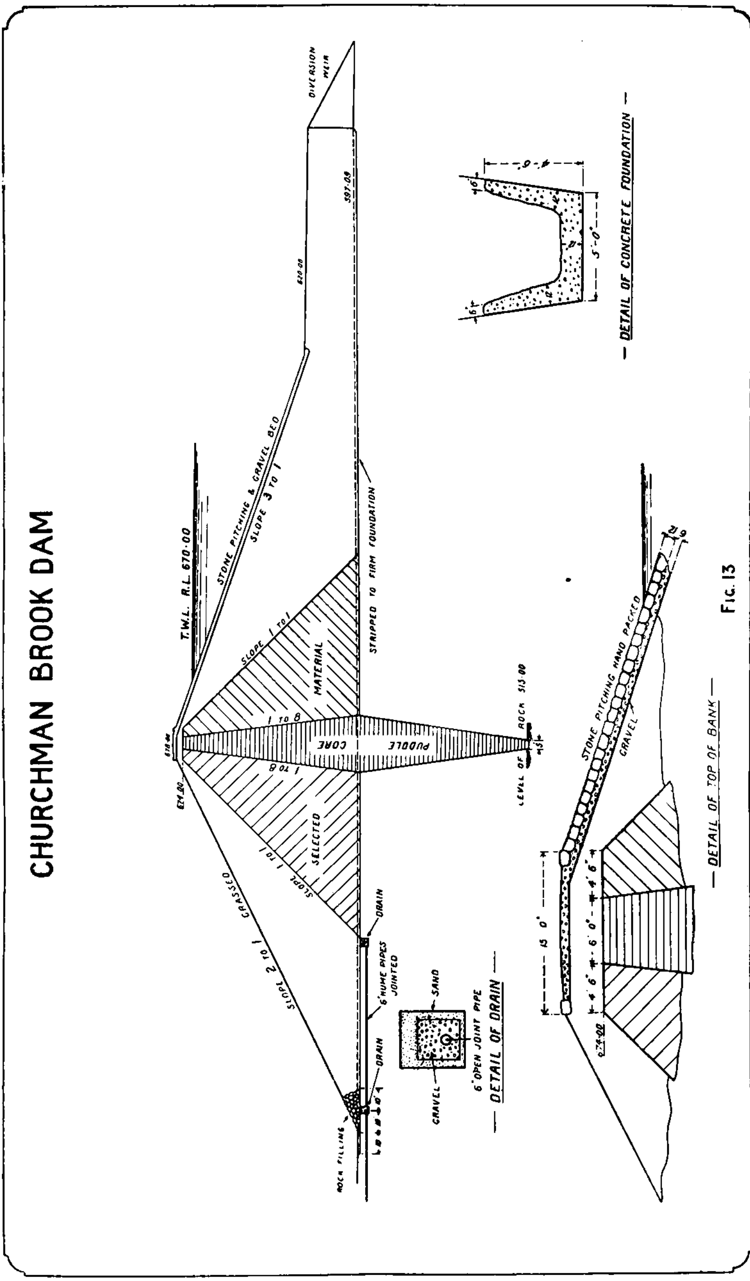

CHURCHMAN BROOK DAM
T.W.L. R.L. 670·00
STONE PITCHING & GRAVEL BED
SLOPE 3 TO 1
DIVERSION WEIR
STRIPPED TO FIRM FOUNDATION
SLOPE 1 TO 1
MATERIAL
SELECTED
1 TO 8
PUDDLE CORE
LEVEL OF ROCK 515·00
SLOPE 2 TO 1
GRASSED
DRAIN
6" HUME PIPES JOINTED
ROCK FILLING
SAND
GRAVEL
6" OPEN JOINT PIPE
DETAIL OF DRAIN
DETAIL OF CONCRETE FOUNDATION
5'-0"
STONE PITCHING HAND PACKED
GRAVEL
15' 0"
DETAIL OF TOP OF BANK

Fig. 13

*Churchman Dam.*

The reservoir impounded by this dam will have a capacity of 500 million gallons. The design provides for an earthen dam (Fig. 13) with a maximum height of embankment of 85 feet. The top width is 15 feet, the upstream face has a slope 3 : 1 and the downstream face 2 : 1. The upstream face has pitching 12 in. thick on gravel 6 in. thick. The puddle core is 6 feet wide at its top, 4 ft. below the top of the bank and has sides battered 1 in 8 to natural surface. Below the natural surface the core reduces gradually in thickness to 5 feet at its foundation.

The bywash level is 8 ft. below the top of the embankment. The water supply off-take pipe and scour pipe are at the same level, 60 ft. below the bywash. They are laid in a tunnel through the rock underlying the eastern end of the dam. Before construction was started, 3 shafts, and 12 bores were sunk on the centre line of the proposed dam to determine the depth of impervious foundation. These showed rock at depths of 44 ft. to 85 ft. below the natural surface.

Consideration was given to alternative proposals for concrete and puddle core. Excellent puddle clay was found available close to the dam site and it was decided, on grounds of lower cost, to adopt puddle.

After preliminary work of clearing the site and installing operating plant, including an electric power line from the Electricity Department's supply at Armadale, active operations were commenced in November, 1923, driving the tunnel for the supply and scour pipes and sinking the valve shaft. The tunnel excavation was for the most part in granite and diorite rock frequently badly fissured and carrying small flows of water. A concrete floor was laid throughout the tunnel, and portions where badly fissured were lined with concrete, and after laying the pipes further portions of the tunnel were filled with concrete to prevent percolation of water from the reservoir to the tunnel.

The sinking of the trench for the puddle core commenced in May, 1925, and work was carried on for the most part in three shifts till completed—Sundays excepted. The depth in the trench reached a maximum of 112 ft. below the natural surface and the lowest elevation reached was 88 ft. below the original stream bed. The total excavation from the core trench was 21,898 c. yds. The material passed through comprised clays, gravel and decomposed granite more or less water bearing (Fig. 14). The trench bottomed throughout on hard solid rock

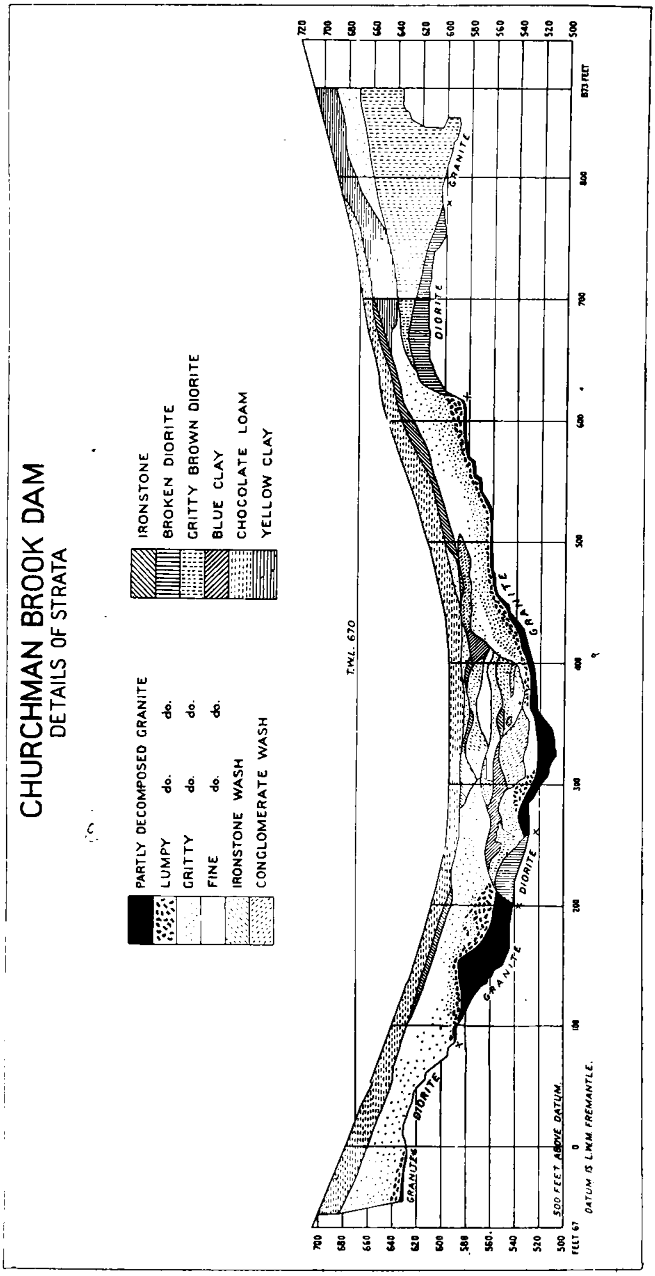

CHURCHMAN BROOK DAM
DETAILS OF STRATA
PARTLY DECOMPOSED GRANITE
LUMPY do. do.
GRITTY do. do.
FINE do. do.
IRONSTONE WASH
CONGLOMERATE WASH
IRONSTONE
BROKEN DIORITE
GRITTY BROWN DIORITE
BLUE CLAY
CHOCOLATE LOAM
YELLOW CLAY
T.W.L. 670
GRANITE
DIORITE
500 FEET ABOVE DATUM.
DATUM IS L.W.M. FREMANTLE.

*Fig.* 14.

—alternately granite and diorite with good close joints in every case under the embankment. Where the joints were water-bearing, grout pipes were fixed and the joints grouted under pressure. The nature of the foundation thus found made it necessary to provide a concrete footing for the puddle core throughout the full length of the foundation as it was not practicable to cut a satisfactory key into the rock itself. The concrete footing provided a floor 12 in. thick, carefully bonded to the rock foundation, and splayed side walls, 12 in. tapering to 6 in. thick and not less than 3 ft. 6in. high. The sides of the trench, as sinking proceeded, were heavily timbered and sheeted with jarrah planks, 2 in. thick for the top 20 feet, and 3 in. thick for all lower levels. The joints between the planking were left about 2 in. open. The timber required was cut largely from the surrounding bush and a saw bench on the works was kept fully employed. Other timber was obtained from a trading saw mill operating on the catchment area and from other mills. The sheeting was placed horizontally supported by vertical posts tommed across the trench. The distance between the toms vertically was 5 ft. and horizontally 7 ft. 0 in. to 3 ft. 6 in. The largest toms used were 26 feet long x 14 in. dia. Generally the toms were about 10 in. dia. The vertical timbers, against which the toms rested, were 12 in. x 6 in., and the sheeting 6 in. to 12 in. wide.

Seepage into the trench necessitated the continuous operation of pumps both during sinking of the trench and refilling with puddle. The pumps used were one 3 in. three-throw pump, belt driven by electric motor, two direct acting Blake pumps, driven by compressed air, and one 4 in. two-stage centrifugal pump, belt driven from 20 h.p. motor. Compressed air for the pumps and for operating rock drills and jack hammers was supplied by an Alley & McLellan compressor belt driven by 64 h.p. electric motor and capable of delivering 300 c. ft. free air at 80 lbs. pressure.

The maximum quantity of water that had to be pumped from the trench was about 25,000 gals. per day. The excavation of the core trench was carried out by hand, the spoil filled into buckets and hoisted to the surface by whips—there were five whips operated by friction winches and one horse whip.

Several hand windlasses were also used in sinking the narrow trenches in the hill sides.

For handling the heavy timbers a travelling steam crane was used operating from a track laid on one side of the trench.

The clay for the puddle core was excavated by hand from the clay pit where it was sprinkled with water and, after weather-

ing, loaded into tipping trucks and hauled by a winch direct to pug mill from which, after being well cut up and mixed, it was dumped into trucks and taken direct to the trench. When depositing the puddle in the deeper portions of the trench, it was conveyed from the surface to the bottom of the trench by chutes, lined with galvanised sheet iron and inclined 2.4 horizontal to 1 vertical, so arranged that the material could be readily delivered where required. As the puddle filling approached the surface, the puddle was dumped direct from the trucks in to the trench. In the trench the new puddle was carefully spread and cut into the puddle already placed and then thoroughly rammed and worked with 17-pound rammers.

The core trench was filled with puddle to the level of the stream bed in August, 1926, the total puddle placed being 12,335 c. yds. Further progress was then greatly hindered by the continuous wet weather from August to November, making the earth fill too sticky and slippery for economical

| Name of Reservoir | Capacity in Gallons. | Height above Low Water Level, Fremantle Harbour. | |
|---|---|---|---|
| | | When full. | When just empty. |
| | | feet | feet |
| Mount Eliza, No. 4 | 13,600,000 | 236 | 215 |
| Mount Eliza, No. 3 | 10,153,000 | 236 | 215 |
| Mount Eliza, No. 2 | 2,413,000 | 236 | 217 |
| Mount Eliza, No. 1 | 784,000 | 236 | 217 |
| Osborne Park, No. 3 | 9,336,000 | 205 | 185 |
| Osborne Park, No. 2 | 1,757,000 | 205 | 185 |
| Osborne Park, No. 1 | 1,757,000 | 206 | 185 |
| Melville Park | 9,664,000 | 200 | 180 |
| Swanbourne Terrace | 1,019,000 | 163 | 150 |
| Claremont High Level | 104,000 | 177 | 166 |
| Claremont Low Level | 800,000 | 150 | 136 |
| Richmond, No. 2 | 1,060,000 | 200 | 185 |
| Richmond, No. 1 | 250,000 | 200 | 185 |
| Greenmount | 1,023,000 | 214 | 193 |
| Greenmount High Level | 24,000 | 429 | 421 |
| Armadale | 25,000 | 303 | 295 |
| Applecross | 38,000 | 104 | 85 |
| Buckland Hill | 4,000,000 | 200 | 180 |
| Total of Service Reservoirs | 57,807,000 | | |
| Lower Bickley Reservoir | 23,350,000 | 255 | 221 |
| | 81,157,000 | | |

*Table VII.*

or good work. The rainfall June to November, 1926, was as follows :—June 11.59 inches, July 20.66, August 9.13, September 7.23, October 7.30, November 3.06, making a total of just over 59 inches for the six months. It was not till November that conditions became suitable for the active prosecution of the work of building the embankment. The plant in use for this work included three steam navvies, three locomotives, side tipping trucks (2 ft. gauge), travelling belt conveyor, horses and scoops. The earth filling excavated by the navvies was loaded into side tipping trucks and brought by the locomotives to the embankment where it was dumped and then picked up and distributed by wheeled scoops over the embankment as required—the wheel scoops and horses serving the purposes of consolidation assisted by watering. About 300 men were employed on the works, working three shifts as far as practicable.

## *Service Reservoirs.*

The service reservoirs now in use are detailed in Table VII. These have a total storage of 81-million gallons. The Mt. Eliza group of service reservoirs (total capacity 26,950,000 gallons) is the main distributing centre for the metropolitan area. From these reservoirs the water will gravitate to the other service reservoirs at Osborne Park, Claremont, Buckland Hill and Fremantle. The reservoirs are well situated to ensure satisfactory supplies to the more thickly populated areas. Additional service reservoirs will be required in the near future for the growing districts at Victoria Park and South Perth, Bayswater and Midland Junction. The first service reservoir, built by the Perth Water Works Company in 1890, of 784,000 gals. capacity is built of brickwork, cement rendered—all others are built of concrete, the more recent having more or less steel reinforcement.

The type of tank constructed in recent years where excavation is in sand as at Mt. Eliza, Osborne Park and Melville, is rectangular in plan, 20 ft. deep with floor 12 in. thick, sides 12 in. thick with 1 to 1 slopes from floor to about 5 ft. below top water level, and vertical gravity section walls thence upwards. Spoil from excavations is used for an embankment supporting the upper portions of the walls up to top water level. Reinforcement is used at the junction of the floor and sides and between the 12 in. sides and the thicker gravity walls above them ; also temperature reinforcement is used in the tops of the walls (Fig. 15).

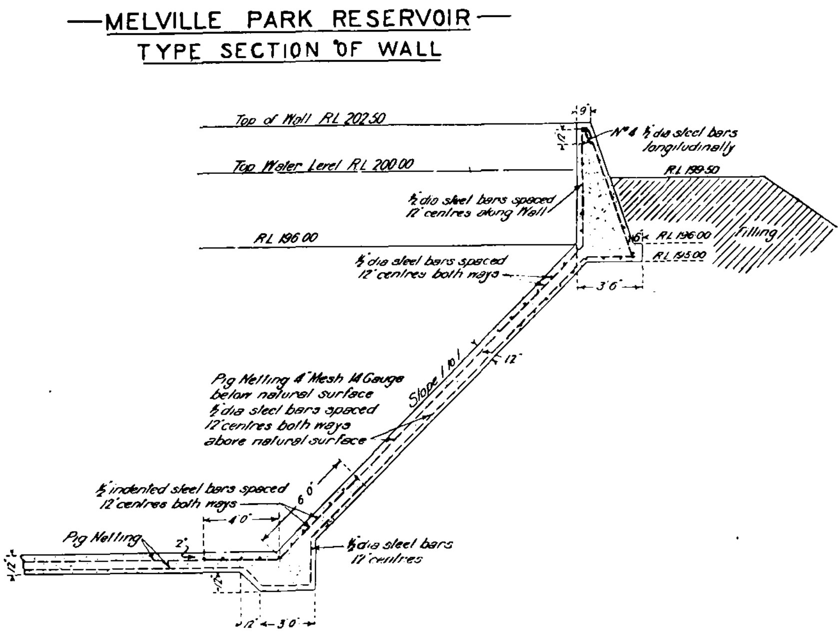



*Fig.* 15.

At Richmond, East Fremantle, a circular service reservoir of 1 million gallons capacity is built in order to make the best of the limited area of the site. The excavation is in limestone. The floor is of concrete, 6 in. thick reinforced in two directions at right angles with ½ in. steel bars at 18 in. centres. The sides have a batter of 1 in 6, and are built of concrete 9 in. thick, where in rock excavations, and thickened to a retaining wall section above the natural rock surface. The floor reinforcement is extended 2 feet up the walls and the junction between the 9 in. wall and thicker gravity section above them is also reinforced with ½ in. steel bars, 3 feet long, spaced at 12 in. centres. An embankment is built up outside the walls to top water level. The reservoir has an effective depth of 15 ft. of water. The top diameter is 122 ft. 9 in. The reservoir is roofed with galvanised iron.

At Buckland Hill, the latest reservoir constructed (Fig. 16), the excavation was also in limestone. This reservoir is rectangular in plan with floor and sides of reinforced concrete. The floor is 240 ft. x 128 ft. x 6in. thick, reinforced with ⅜ in. dia. steel bars at 18 in. centres in both directions parallel with the sides. The sides are battered 1 in 6. The concrete lining to the sides is 6 in. thick, where in excavation, and above this

is 12 in. thick supported by a limestone rubble masonry wall in lime mortar and embankment up to top water level. The reinforcement in the walls, where 6 in. thick, is composed of horizontal rods, ⅜ in. dia. at 18 in. centres, and vertical rods, ⅜ in. dia. at 36 in. centres. Where the sides are 12 in. thick, the same diameter of rods is used and spacing reduced to 9 in. for horizontal, and 18 in. for vertical reinforcement. Additional reinforcement is used at changes of section of wall from 6 in. to 12 in. The arrangement of the reinforcement bars at the junctions of the walls at the corners of the reservoir is shown in Fig. 16. All the horizontal bars in each wall are extended straight to within 2 in. of the end of the concrete—the bars of each wall

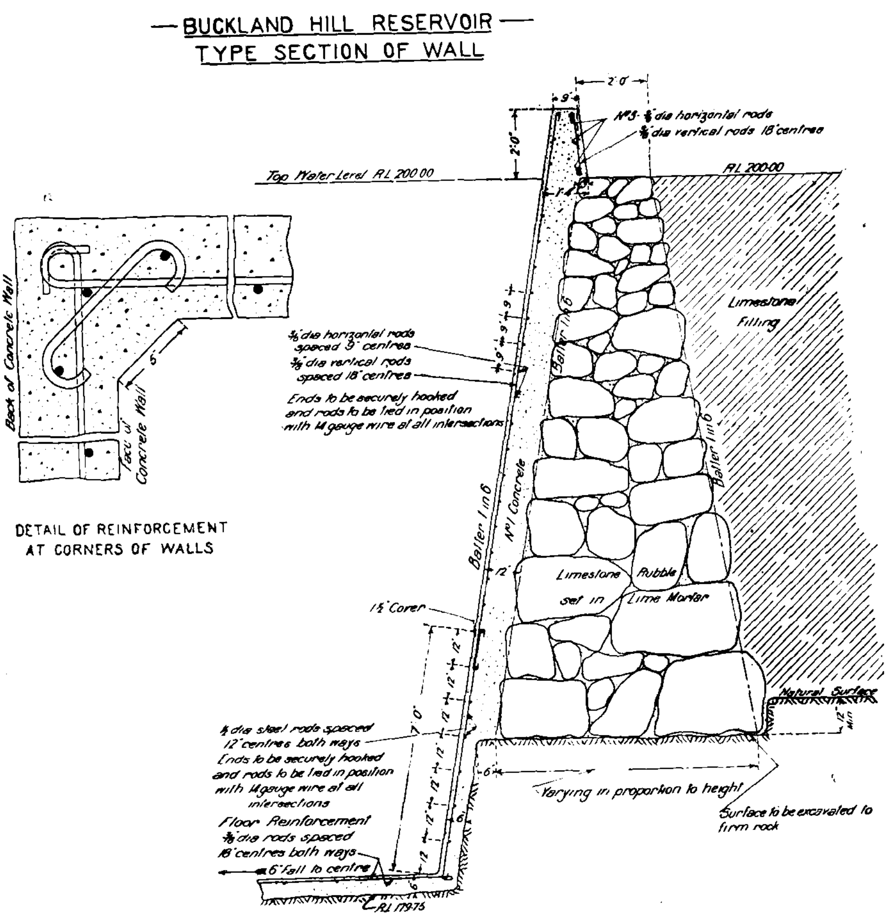



*Fig.* 16.

## Lengths of Water Mains of Various Sizes in use Dec 31st 1926.

| Diameter | Tubing 1" to 2" | 3" | 4" | 5" | 6" | 8" | 10" | 12" | 13" | 14" | 15" | 16" | 18" | 20" | 21" | 24" | 30" | 36" | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M C F | M C F | M C F | M C F | M C F | M C F | M C F | M C F | M C F | M C F | M. C F | M C F | M C F | M. C F | M C F | M. C F | M C F | M. C F | M C F |
| Steel | | | | | | | 1-54-32 | | | | | 1-60-39 | 2-53-15 | 2-42-0 | 10-53-18 | 0-10-33 | 14-15-07 | 16-75-08 | 50-44-20 |
| Reinforced Concrete | | | | | | | | 1-32-45 | | | 0-50-31 | | 2-11-03 | | 2-11-40 | 3-16-42 | 2-12-00 | | 11-54-29 |
| Cast Iron | | 123-74-29 | 114-30-09 | 0-74-33 | 43-54-27 | 46-10-47 | 1-40-56 | 30-61-7 | 9-72-00 | 0-54-50 | | 1-70-00 | 3-08-25 | | 5-39-53 | 8-34-04 | 3-05-14 | 0-49-0 | 394-39-24 |
| Tubing | 136-14-28 | | | | | | | | | | | | | | | | | | 136-14-28 |
| Unclassified | Mains laid previous to inception of Metropolitan Water Supply Department 1910 Mainly 6", 4" and 3" C I and W I Tubing | | | | | | | | | | | | | | | | | | 180-26-38 |
| | | | | | | | | | | | | | | | | | | | Total Length = 773-19-07 |

Table VIII.

overlapping those of the other wall, and in addition diagonal bars are used across the corner.

## *Water Mains.*

The principal mains for distributing the water from the service reservoirs at Mt. Eliza are a 36 in. line into the city via Mount Street, a 21 in. via Havelock St., an 18 in. via Thomas Street, and a 30 in. westwards to Nedlands. The latter main continues 30 in. to Claremont, and thence 24 in. to Fremantle and Melville Reservoir, with a 24 in. branch to Buckland Hill Reservoir. The 18 in. and 21 in. mains mentioned join at Oxford Street and the 18 in. main continues thence to North Beach Road where it joins with a 24 in. main to Osborne Park Reservoir. From this reservoir, there is a second 24 in. main eastward supplying North Perth and Mt. Lawley districts. From Loftus Street Pumping Station there is a 21 in. pumping main, of steel pipes, to Mt. Eliza. This main has been in use since 1904 and has many perforations due to pitting. From Roberts St. pumping station there is a 21 in. c.i. main to Osborne Park Reservoir, and from Fremantle Pumping Station to Melville Reservoir the rising main comprises 18 in. and 21 in. pipes—the lower pressure sections being of Hume concrete pipes and the rest cast iron. The supply from Mundaring Reservoir is brought to Greenmount service reservoir by means of 13 in. dia. c.i. pipes. From Greenmount Reservoir, the main is of 16 in. dia. c.i. pipes to Midland Junction, and from Midland Junction two mains, 12 in. and 8 in., are laid along the northern side of the Swan River to North Perth. These pipes connect at Guildford with an 8 in. main from Victoria Park via the southern side of the Swan River. Other mains, 8 in. and over, are a 21 in. main in Cambridge Street, Leederville, 18 in. and 12 in. mains supplying South Perth, and 8 in. main from Queen's Park to Fremantle for supplying Hills water for the Railway Department, shipping and wool scouring works at Fremantle. Table VIII. shows lengths of mains of various diameters in use.

The first pipes used in connection with the Perth Water Supply were 12 in. c.i. pipes imported from Glasgow and laid in 1891 from Victoria Reservoir to Mt. Eliza. The pipes were ½ in. thick and have suffered badly from corrosive action of the water. For many years there have been frequent bursts due to the decreased strength of the pipes owing to corrosion. Inspection of samples of these broken pipes shows the pipe walls when cleaned to be of full original thickness but the substance of the pipes has been changed on the inner face from

iron to a soft material resembling black lead, to varying depths of $\frac{1}{8}$ in. to $\frac{1}{4}$ in. The action of the water has dissolved away, or changed, the iron in the sides of the pipe to these depths and left some of the pipes too weak to stand the working pressure. The sound metal in these pipes is a soft grey iron of good quality.

The second main, laid in 1897, from the foothills below Victoria Reservoir to Mt. Eliza to bring more water from this reservoir, included some 18 in. and 20 in. c.i. pipes imported from Sydney. There have been many bursts of these pipes although the pipes are of ample thickness to stand the pressure. The fractures show sound metal for the full thickness of the pipe. There is no appreciable corrosion and no softening of the material of the pipe, but the fractures show that the metal is white and hard. The defective quality of these pipes is evidently due to improper care in manufacture, the pipes having been removed from the moulds whilst too hot, and severe internal stresses consequently produced by unequal and too rapid cooling. Bursts have occurred in other large cast iron pipes in various parts of the system that can be attributed only to the same cause, but they have been few. Similar bursts are frequently referred to in water works literature from various parts of the World and show the necessity for insisting, in Standard specifications, on definite and clear provisions to ensure that the safety of the pipe will not be jeopardised by their removal from the moulds, whilst too hot or showing any colour of heat, and by irregular cooling.

The pipe main laid in 1897, in addition to the cast iron pipes referred to above, included 8 miles 55 chains of 21 in. dia. steel pipes. These were riveted pipes, $^5/_{16}$ in. thick, with welded steel sockets riveted to the pipes. This main is still in service but has suffered much from perforations due to pitting from inside. The outside of the pipe, where laid in sand, is in good condition. The number of perforations during the year 1917-18 was 60 and since then they have varied from 16 to 85 per year—the total number during the past 10 years being 465.

The reticulation pipes are for the most part of cast iron, from 3 in. dia. upwards, but there are many miles of galvanised pipes, $1\frac{1}{2}$ in. and 2 in. dia. in use in the outskirts. A length of 50 chains of 8 in. wood stave pipe was laid in 1912 in Victoria Street, Fremantle and over the North Fremantle Road Bridge, but it had to be removed in June, 1922, on account of deterioration of the joints and consequent excessive cost of maintenance.

In 1921, the first Hume reinforced concrete pipes were laid to take the water from the bore at Hector Street to the pumping

station at Roberts Street, Osborne Park. The main comprises 52 chains of 21 in. dia. pipes. The maximum pressure is 7 lbs. per sq. inch. These were followed, in 1922, by 50 chains of 15 in. dia. pipes from King Edward Srteet bore to Hector Street bore under a maximum pressure of 15 lbs. per sq. inch. In 1922, also, 50 chains of 12 in. dia. Hume pipes were laid in North Beach Road, Mt. Hawthorn, subject to a maximum static pressure of 60 lbs. per square inch, and 162 chains of 24 in. pipes were laid from Osborne Park Reservoir to North Perth with a maximum pressure of 52 lbs. per square inch.

In 1923, 102 chains of 18 in. Hume pipes and 67½ chns. of 21 in. were laid as part of the pumping main from the Fremantle Pumping Station to Melville Reservoir. The maximum pressure in this case is 52 lbs. per square inch.

In 1925, 169 chains of 30 in. Hume pipes were laid from the reservoirs at Mt. Eliza westward through King's Park to Nedlands with a maximum pressure of 93 lbs. per square inch, and 68 chains of 24 in. were laid at Osborne Park. The total length of Hume pipes laid to date is nearly 11 miles, with diameters ranging from 12 in. to 30 in. The greatest pressure to which they are subject is 93 lbs. per square inch in the case of the 30 in. pipes just referred to.

The reinforced concrete pipes laid and put into service up to date have given uniformly entire satisfaction. The pipes are in all cases, except East Fremantle, laid in sand. At East Fremantle, the excavation in some cases was in limestone rock. Where this happened, a good bed of sand was placed in the bottom of the trench before laying the pipes. In only two cases has it been necessary to effect repairs to Hume pipes after having been put into use. These cases were slight cracks in collars on 30 in. and 24 in. pipes, respectively. Repairs were effected by emptying the mains and surrounding the cracked collars with a larger reinforced concrete collar built in position.

The specifications to which all the Hume pipes have been laid provide that the leakage should not exceed certain amounts. In the case of the 12 in. pipes, 50 chains in length, laid in North Beach Road in 1922, the allowable leakage was 500 gallons per mile per day. Tests made under working pressure —50 to 60 lbs. per sq. in.—showed leakage of 4,326 gallons per mile per day when the main was first filled. The leakage rapidly decreased to 1,400 gallons per mile per day in 11 days and to 480 gallons in a further 40 days. The leakage continued to decrease and in 5 months after laying it was 234 gallons per mile per day. A test made recently (12th October, 1926), showed leakage of 88 gallons per mile per day. At the

time this test was made, the pipes were unearthed at six places for external inspection and in every instance both the pipes and joints were found sound and free from any sign of seepage. This pipe line runs parallel to a tramway at a distance of 24 feet and there is heavy motor traffic at 12 feet from the pipes. A pipe was also taken out of this line in October, 1926, for the purpose of inspecting the inside of the pipes. The pipe removed, and adjoining pipes as far as could be seen in each direction, were in perfect condition, showing no sign of deterioration after 4½ years' service. Leakage tests on the 30 in. Hume pipe main, 172 chains in length laid in King's Park in January, 1925, showed, under working pressure which varied from 10 lbs. per sq. inch at the outlet from the reservoir to a maximum of 93 lbs. per sq. inch near Nedlands, a leakage of 4,773 gallons per mile per day shortly after the main was first filled. In 3 months the leakage was reduced to 2,300 gallons per mile per day, in 6 months to 870 gallons, and at 9 months from date of filling it was 349 gallons per mile per day. The contract allowed a leakage of not more than 2,500 gallons per mile per day.

Where Hume pipes are used, it is usual practice for the excavation of the trench to be done by the Water Supply Department, and the supply, delivery, laying and jointing by the Hume Pipe Company. In laying concrete pipes with cement joints, it is essential that they should be well anchored to prevent expansion. If the pipes are allowed to expand they will do so but in contracting they are very liable to crack as they have little strength in tension longitudinally, particularly at the joints, and are prevented from contracting freely by the large projecting joint rings. If the pipes are well anchored against expansion, particularly at places where movement is likely to occur, as at bends and junctions, there need be no movement and consequently no cracking. The pipes being laid dry tend to expand when filled with water and thus put themselves in compression longitudinally. Increase in temperature will only increase this compression and decrease in temperature will only relieve this compression. Expansion joints should not on any account be used with pipes with cement joints laid in the ground.

With regard to the life of reinforced concrete pipes, well made and well laid, there is no data whereby a reasoned estimate may be made. The first reinforced concrete pipe in Perth was a 12 in. Monier pipe laid in 1918 conveying water from Walters Brook to the Power House, East Perth. A recent examination of the outside of this pipe at several places showed

no sign of deterioration. The Hume pipes laid in North Beach Road in 1922, and recently inspected as already described similarly, show no signs of deterioration either inside or out. In the same period there would be a material depreciation in iron or steel pipes with the ordinary pipe coatings hitherto used. It may, therefore, be safely said that the life of a well-made reinforced concrete pipe is greater than that of cast iron pipes as hitherto used, which has been generally taken, for ordinary conditions, at 80 years. There is no apparent reason why Hume pipes should not last several times this period where the pipes are subject to low or moderate pressures and laid with cement or cement protected joints. American Water Works practice affords examples of cement-lined pipes going back to over 80 years, but the practice of cement lining did not come into common use till the advent of the Hume process made it possible to do this lining economically and at the same time in a highly efficient manner.

## *Pipe Coatings.*

Till recently there has been no satisfactory protective coating applied generally to iron and steel pipes in any part of the world. Everywhere pipes have been given thin coatings of various materials with short lives—four or five years—and the pipes have accordingly corroded badly where corrosive waters are carried. The spinning process provides a means for greatly improved workmanship and enables a thick uniform coating to be applied of either cement or bitumen, which are the two most effective materials found in practice. Cement as a pipe coating has in itself the power of removing the corrosive quality of the water since the water, in percolating through the cement lining, will be rendered alkaline by taking up lime from the cement. This power, too, is effective even if the cement lining be cracked and not adhering closely to the metal. Bitumen, on the other hand, can protect the metal only by remaining free from cracks or perforations and preventing access of water to the metal. If the water has access to the metal through a perforation or crack in a bituminous lining, corrosion will occur in the nature of pitting. Thick bitumen coatings can now be made to withstand exposure to the summer sun without flowing and, at the same time, be pliable at low temperatures, but they have not yet been subject to the one test above all others, that of time, under working conditions. It remains yet to be proved whether the modern spun cement or bituminous coating will give longer protection to water

pipes—but it is certain they are both infinitely better than the coatings hitherto generally used.

Samples of pipes lined by the centrifugal process with bitumen mixture, designed to withstand high temperatures, have recently been obtained from England and put into service in the reticulation mains for testing purposes. A 21 in. steel pipe was lined with cement by the centrifugal process at the Department's workshop in 1920 and half submerged in one of the service reservoirs at Mt. Eliza. The coating on this pipe has remained in excellent condition although only about $\frac{1}{8}$ in. thick and applied to a rusty pipe. The first cement lined pipes used in the system were the 36 in. steel pipes already referred to, which were laid in January, 1926, up the steep approach to Mt. Eliza. The lining in this case was done by placing the mortar in the pipe as it lay on the ground over one fourth of the circumference and trowelling to even thickness. When the first strip thus made was set, the pipe was rolled a quarter turn and another strip made, and so on. In August, 1926, 77 chains of 21 in. cast iron pipes were lined with cement mortar, $\frac{1}{2}$ in. thick, of 1 part cement to 2 parts sand, by the centrifugal process and laid in Cambridge Street, Leederville.

### *Treatment of Water to Prevent Corrosion.*

The water from the Hills is found to be highly corrosive and, in order to render it less corrosive, it has been the practice for many years past to treat the water drawn from Victoria Reservoir with lime (160 lbs. quick-lime to one million gallons) and to add further lime at the outlets from the service reservoirs. There can be no doubt much benefit has been derived from this treatment although it cannot entirely prevent corrosion and the formation of rust nodules in the pipes. In the large mains, the effect of corrosion, and consequent formation of tubercles of rust, is to reduce the carrying capacity of the mains and produce leaks by perforations in steel mains from pitting. In the smaller mains, the corrosion not only reduces the carrying capacity of the pipes but also gives rise to serious discoloration of the water, particularly in the early summer, and after the mains are emptied owing to the disturbance of the rust from the sides of the pipes by the high velocities occasionally attained by the water in such cases.

A highly effective remedy against corrosion is de-aeration but as the water quickly absorbs air when exposed, it can be relied on only where the water, when once de-aerated, is kept from exposure to the air. The first application of de-aeration

| | CHEMICAL ANALYSES GRAINS per GALLON | | | | | | | | HYGIENIC ANALYSES PARTS per 100,000 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Chlorine | Sodium Chloride | Alkalinity Sodium Carbonate | Total Solids | Hardness Temp | Hardness Perm | Iron | Reaction P H | Ammonia Free | Ammonia Albuminiod | Oxygen absorbed in 4 hours | Nitrogen as Nitrates | Nitrogen as Nitrites | Reaction P. H. |
| Victoria Reservoir | 9·80 | 16·16 | | 18·55 | 0·70° | 1·58° | | 6·9 | | 0 028 | 0·072 | 0·016 | | 6·5 |
| Bickley Brook | 6·9 | 11 3 | | 14·4 | 0·80° | 1·30° | | 7·0 | | 0·030 | 0·108 | 0·020 | | 6 5 |
| Narrogin Brk Arms | 6·2 | 10·2 | | 13 2 | 0·70° | 1 60° | | 6·9 | | | | | | |
| Churchman Brook | 5·2 | 8 6 | | 15 9 | | | | 6·9 | | 0·012 | 0 011 | 0·016 | | 6 5 |
| Canning River | 12·6 | 20·7 | | 21 0 | | | | 9·8 | | 0·014 | 0 029 | 0 013 | | 6 5 |
| Wungong Brook | 8·7 | 14 3 | | 16 7 | | | | 6 8 | | 0·018 | 0 034 | 0·013 | | 6 5 |
| | | | | | | | | | | | | | | |

Table IX.

was made in this State in connection with the Goldfields Water Supply Main. De-aeration has the advantage of affording protection to all pipes through which the water passes before it is again exposed to the air so that, if it is practicable to deliver the de-aerated water into the reticulation system without passing it through open service reservoirs, the benefit of freedom from corrosion may be secured to the reticulation and service pipes as well as the trunk mains. A question that must be settled before the use of de-aerated water can be recommended in the reticulation system is whether the de-aerated water will remain good and potable during its passage through the system. Lime treatment for the reduction of corrosion was tried on a large scale some years ago, also on the Goldfields Water Supply 30 in. main, and proved to be not wholly effective in preventing corrosion, although a coating of lime of material thickness was deposited on the sides of the main for a great part of its length.

### *Purity of the Water.*

Bacterial examinations of the water supplied to Perth show that the bore waters are sterile, and that the Hills waters have many bacteria and occasionally, particularly in winter, B. Coli. There is very little habitation on the catchment areas and the Department controls and enforces strict sanitary arrangements. The occasional appearance of B. Coli has made it necessary to take the precaution of chlorinating the waters as they are drawn from the various diversion weirs. Five chlorinators are in use—three Wallace Tiernan and two Patterson. Each chlorinator is capable of delivering 12 lbs. of chlorine gas per day, sufficient for 2½ million gallons of water, using chlorine at the rate of 0.5 part per million. Bacterial tests made with the chlorine applied at this rate have shown no trace of B. Coli in the treated water. The water taken from the diversion weirs on the Canning and Wungong was found to be only very slightly turbid at times of the heaviest floods experienced during the winter of 1926, which were the heaviest on record, and at other times is remarkably clear and does not require filtration.

The Perth metropolitan area is fortunate in having at its command first an artesian water supply of large capacity, of no mean quality, and of a purity that is above suspicion; secondly, an almost inexhaustible ground water supply, highly suitable for garden purposes, available by pumping from wells

generally of shallow depths ; and; thirdly, large catchment areas in the Hills at no great distance from the city, with practically no settlement, producing streams of clear, pure water, and requiring only the services of the Engineer to direct the economic utilisation of the resources there provided by Nature to ensure supplies of water of high quality for domestic and industrial purposes for all time to come.

[The paper is illustrated by Figs. 1-16 in the letterpress and Tables I-IX are included.]